THE RESIDUAL EFFECTS OF SILICON, PHOSPHORUS AND SOIL pH ON YIELD AND NUTRIENT UPTAKE OF A RATOON SUGARCANE CROP

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INTRODUCTION

It has been known for almost a century that the element silicon affects the nutrition of sugarcane and other gramineous crops. Recently, both producers and researchers have determined that applications of Si slag can increase sugarcane yields in some soils. In a field trial conducted at the Kauai Branch Station on a highly weathered Humic Ferruginous Latosol (Typic Gibbsihumox), Fox et al. (1967) reported that sugar yields increased approximately 12 tons per hectare with the application of 4.5 tons TVA slag per hectare. Clements et al. (1967) reported that on Kilauea Sugar Company, Kauai, application of 8 tons Si slag per acre resulted in 34 percent more sugar in the plant crop and 40 percent more suger in the first ratoon crop. Clements expected the differences in yield between treated and untreated plots to widen in the second and third ratoon crops. These beneficial results as well as others have encouraged additional research on the mechanism of the yield response of sugarcane to Si application.

The study of Si in Hawaii began with Maxwell's work in 1898 (quoted from Moir 1936). Maxwell found that the Si content of soils in high rainfall areas was very low and speculated that the low Si content might affect cane yields. No further work was done on Si until McGeorge (1924) concluded that Si affected P assimilation by plants. Silicon nutrition was not studied again in Hawaii until 1955 when Sherman et al. reinvestigated McGeorge's work and came to the same conclusion.

There are several different views regarding the mechanism of yield gains due to Si applications. The three major types of Si response reported are: (1) effects on soil fertility, (2) effects on the normal growth of plants, and (3) effects on the resistance of plants to disease.

Monteith and Sherman (1963) reported that in a Humic Ferruginous Latosol (Typic Gibbsihumox) calcium silicate increased sudangrass yields due to increased availability of soil P and not to a decrease in active Al, while in a Hydrol Humic Latosol (Typic Hydrandept) increased yields were accompanied by a reduction of "toxic" Al by the Ca in the slag. Suehisa et al. (1963) suggested that Si enhanced the availability of P in the soil by either reducing the P fixing capacity of the soil or by substituting for P in the soil. Other researchers interested in the effects of Si on sugarcane and rice nutrition have also suggested that interactions of Si with P, Al, Mn, and Fe are responsible for the observed yield responses following Si applications.

Workers investigating the physiological aspects of the Si response have found that Si affects plant growth habit and disease resistance. Okamoto, Y. (1957) and others have observed that rice plants grown with Si have erect leaves while rice plants grown without Si have drooping leaves. Silicon is thought to reduce lodging and increase disease resistance in rice by increasing the culm strength.

Commercial use of silicates by the sugar industry appears very profitable if reported yield increases are realized; but costs are high. It becomes necessary to identify areas which would benefit from Si application and to determine mechanisms for the response to the applications. To accomplish this objective it is necessary to understand the relationships between Si and other growth factors. The objectives of this study were (1) to investigate the relationships among Si, P, and soil pH treatments and their residual effects on nutrient composition and yield of a ratoon crop of sugarcane; (2) to study the influence of Si on the availability of soil P and the internal P requirement of sugarcane; and (3) to study the effects of residual Si, P, and soil pH treatments on the availability and uptake of soil nutrients other than P.

LITERATURE REVIEW

Soil Silicon

Iler (1955), Jones and Handreck (1965), Fox *et al*. (1967) and others agree that Si is present in an acid soil in the form of monosilicic acid ($Si(OH)_4$). The solubility of monosilicic acid in the soil depends mainly on soil pH and the quantity of sesquioxides present. Raupach (1957) noted that the amount of Si in the soil solution decreased as pH increased from 3 to 7, fell sharply to pH 8 and then increased as pH increased above 9. Beckwith and Reeve (1963) reported that between pH 4.0 to 9.0, oxides and hydroxides of Fe and Al sorb monosilicic acid. Aquave and Tinsley (1964) observed that P added to solutions decreases the pH required for precipation of Si from pH 3 to 2 in the presence of Fe and from pH 4 to 3 in the presence of Al. Between pH 4 and 7 the Si was slightly more soluble in the presence than in the absence of P. They also observed that the effect of molybdate on Si solubility was similar to that of phosphates. Ayres (1966) and Miller (1967) observed an inverse relationship between extractable soil Si and pH. On the other hand, Cheong (1967) found a highly significant positive correlation between extractable soil Si and pH when five great soil groups were considered together. However, only the Low Humic Latosols (Tropeptic Haptustox) showed such a positive correlation when the great soil groups were studied individually.

Halais and Parish (1963) in Mauritius found that applications of powdered basalt ranging up to 100 tons per acre resulted in increased sheath Si concentrations and increased cane yields. This yield increase was attributed to the improved physical condition of the soil and not to changes in the uptake of nutrients. Additions of colloidal Si to sand culture were believed to increase yield by increasing the water holding capacity of the sand according to Dix and Rauterberg (1934).

Onikura (1959), working with volcanic ash soils of Japan, found that Si application caused the formation of amorphous Al and/or Fe silicates from allophane and sesqui-hydrous oxides and caused hydrated halloysite to be transformed to a 16 Å mineral. Onikura also found that the cation exchange capacity of the clay fractions increased with Si application. The same affect of Si on cation exchange capacity was found by Mahilum (1965) on a Hydrol Humic Latosol (Typic Hydrandept). Uchiyama and Onikura (1956) applied soluble Si and calcium hydroxide to paddy soils and allowed them to stagnate for 4 months. They found that when Si was added alone, the quantity of 2:1 clays increased; however, when Si was added with Ca, increases of chloritic or kaolinitic minerals were observed.

Effect of Silicon on Soil Phosphorus

Many workers have attributed the beneficial effects of Si to enhanced P assimilation. McGeorge (1924) studied the influence of Si on P availability in Humic Ferruginous Latosols (Typic Umbriorthox) and found no difference in total soil P at any elevation; however he found a definite relationship between available Si and P as measured by response of sugarcane. Lemmerman *et al.* (1925) working with sand cultures concluded that Si cannot replace P in the metabolism of the plant and all yield increases from Si applications were due to increased P availability. Fisher (1929) believed the main effect of Si was to increase the availability of soil P through anion exchange reactions.

The effects of the hydroxyl, sulfate and silicate anions on plant yield were studied by Toth (1939) who concluded that the hydroxyl and silicate anions resulted in "P complex degradation". He noted that yields increased when calcium and magnesium silicates were added but found no relationship between yield and available P.

Dutt (1947) compared the addition of water soluble potassium silicate with other cultural treatments and found that the highest dry matter yields and the highest Si and P uptake occurred in the potassium silicate treatment. He also reported that the addition of potassium silicate induced better and more stable soil structure than the usual organic matter or green manure practices.

Applied calcium, magnesium and sodium silicate were reported by Dewan and Hunter (1949) to have no effect on the yield or P uptake of soybeans. The yield and P uptake of sudangrass were also unaffected by applied Si 8 weeks after application. However, plant Si increased significantly due to Si application in both crops.

More recently, Chu et al. (1955) found that when sodium silicate was applied to a Humic Latosol (Humoxic Tropohumult) and a Low Humic Latosol (Tropeptic Haptustox) the yields of sudangrass were tripled on the Humic Latosol and were unaffected on the Low Humic Latosol. They noted that the typical P deficiency symptoms of sudangrass were eliminated by the Si addition. Ikawa (1956), extending Chu's work, concluded that Si application was beneficial on a Humic Latosol (Humic Tropohumult) but not on a Low Humic Latosol (Tropeptic Haptustox), a Humic Ferruginous Latosol (Typic Umbriorthox) or a Dark Magnesium Clay (Typic Chromustert). He also found that P was more easily extracted from soil following application of Si.

Raupach and Piper (1959) believed that Si did not change the type of reaction which fixed soil P but rather altered the equilibrium constants involved. They concluded that any effect of Si must therefore be transient.

Monteith and Sherman (1963) reported that in a Humic Ferruginous Latosol (Typic Umbriorthox) calcium silicate increased sudangrass yields due to increased available P and not due to a decrease in active Al. Suehisa et al. (1963) drew similar conclusions when they found that application of 1120 kilograms of sodium metasilicate per hectare caused 76% more P to be absorbed by the test crop from the Si treatment than by the control.

The effects of Si on the uptake of P were studied by Hunter (1965) who concluded that large amounts of Si increased the availability of soil P by anion exchange. Furthermore, he found no evidence that Si substituted for P in the plant.

Teranishi (1968) found that soil P extracted by the modified Truog method was not increased by application of 833 kilograms Si per hectare, but was slightly increased by application of 1666 kilograms Si per hectare.

Effect of Silicon on Other Nutrients

Schollenberger (1922) found no evidence that Si affects P assimilation and suggested, on the basis of a field trial, that N may be more abundant in the soil when Si is applied. MacIntire (1927) observed that Mg toxicity of tobacco, caused by the application of MgO, was decreased by the application of an equal amount of SiO_2, while a fourfold increase in SiO_2 application nearly eliminated Mg toxicity. The formation of magnesium silicates and carbonates was thought to be responsible for the reduction in Mg toxicity.

MacIntire and Sterges (1952a) conducted a ten-year lysimeter study and found that the application of an adequate amount of soluble Si (as Si slag) to fallow soils increased the amounts of F, P and Ca, but decreased the amounts of K and Mg in the leachate. MacIntire and Sterges (1952b), reporting on another phase of their lysimeter study, found that limestone as well as Si slag decreased the amounts of K and Mg leached. They also observed that the quantities of nitrate and sulfate in the leachate were increased by both the limestone and slag treatments.

Exchangeable bases and extractable S were increased by the application of calcium silicate slag to a Hydrol Humic Latosol (Mahilum, 1965).

Clements (1967) believed that calcium silicate and calcium carbonate may increase cane and sugar yields by eliminating from the soil solution toxic excesses of the micro plant nutrients as well as of Co, Ni, Al, Ti and Pb. He proposed that although many other compounds can eliminate these toxicities, Si may give more permanent and more complete correction.

Plant Silicon

It is widely known that species absorb different amounts of Si and that the graminaceous species accumulate much higher amounts of Si than the non-graminaceous species. Rice and sugarcane have given the largest responses to Si applications, however other graminaceous crops also appear to benefit from Si application. Among the non-graminaceous crops, sugar beets have shown large responses to Si application (Raleigh, 1945). The Si content of various plant species is highly dependent on the supply of soil and fertilizer Si (Teranishi, 1968; Fox *et al*., 1967; Ali, 1966; Ayres, 1966; Clements, 1965a, 1965b; Jones and Handreck, 1965).

Silicon is believed to occur in plants in the form of plant opal, silica gel and monosilicic acid. Lanning *et al*. (1958) using x-ray diffraction and petrographic techniques found that Si was in the form of plant opal in sorghum, wheat, corn, sunflower and tomato while in lantana it was in the form of plant opal and α quartz. Yoshida *et al*. (1959) working with infrared spectrophotometry reported that Si in rice is in the form of Si gel. Studies of the xylum sap of several species have revealed that Si in the roots is transported to the top in the form of monosilicic acid (Handreck and Jones, 1967; Okuda and Takahashi, 1964).

Several workers have reported that Si is not distributed uniformly in plants. Mitsui and Takatoh (1963b) found that most of the Si^{31} absorbed by rice roots was rapidly transported upward and accumulated in localized spots and along the margins of leaves. Silicon in oats was reported to accumulate in the leaves and inflorescences (Handreck and Jones, 1962). Fox *et al*.

(1969) studied TCA (trichloro-acetic acid) soluble Si and total Si in sugarcane and found that TCA soluble Si was highest in the young leaves, sheaths and stalk internodes and generally decreased with the age of the plant part, while total Si in the leaves and sheaths increased with age until the leaves were mature, after which there was little or no increase. On the other hand, total Si in the internodes first increased and then decreased with age.

Jones and Handreck (1967) concluded that the Si distribution data available support the thesis that Si moves passively in the transpiration stream and is deposited in regions where transpiration is highest. However, Takahashi et al. (1958) observed that Si was absorbed by the rice at a high rate against a concentration gradient and they found no correlation between transpiration and absorption of Si. The data of Fox et al. (1969) suggest that the deposition of opal in plant tissues is associated with growth.

There has been much speculation on the effect of Si on plant growth. Hall and Morison (1905) and Lemmerman (1925) observed that Si, like P, increases grain yield. However, they found no evidence that Si causes better utilization of P in the plant. Akhromeiko (1934) concluded that SiO_2 increases plant growth through direct stimulation of vital processes. He also observed that N nutrition was not affected by Si application. Ayres (1966) studied the effects of all the nutrients present in Si slag on the growth of sugarcane and concluded that only Si could account for the pronounced yield increases observed. Fox et al. (1967) observed that silicate response did not result from improved P nutrition because, in a situation where Si greatly increased sugarcane production, a fourfold increase of applied P had little effect on yield.

Silica was reported to be indispensable for the growth of sugar beets by Raleigh (1939). He also observed the following effects when Si was deficient in sugar beets: the growth of primary roots is retarded and some secondary roots are produced, the outer leaves tend to wilt (especially in an atmosphere with a high evapotranspiration potential), leaves develop anthocyanin color along the veins, in young plants the cotyledons yellow and die, and the frequency of damping-off increases.

Some insight into the role of Si in plant nutrition is being gained by several researchers Umemura et al. (1961) reported that acid phosphotases of Irish potato and rice plants were inhibited by both ionic silicate and colloidal Si; however, the activity of sweet potato phosphotase was not affected by the Si treatments. Injuries to rice and barley by excesses of Fe, Mn and As were reduced by Si application according to Okuda and Takahashi (1962) while injury from Cu, Al and Co were not affected. They also concluded that Si absorbed by the plant increased the oxidative power of the roots. In another paper, these same authors (1963) reported that the metabolic pathways of Si and P are completely separate. Mitsui and Takatoh (1963c) observed that aerobic respiration inhibitors and 2,4-dinitrophenol inhibit Si uptake The effects of fertilization and Si content on several forage grasses in Canada were studied by Bezeau et al. (1967) who reported a significant inverse correlation between percent protein and percent Si in the forage.

Rothbuhr and Scott (1957) studied the uptake of Si and P by wheat plants grown in solution culture and found that added P depressed the uptake of Si slightly, and added Si increased the absorption of P. They also reported that considerable amounts of Si were taken up by the plant within one-half hour after Si was added. They concluded that the metabolism of Si and P are closely related.

The relationship between Si and Mn in barley was studied by Williams and Vlamis (1957a) who found that Si altered the distribution of Mn in the leaf but did not prevent its uptake by the plant. These researchers reported in another paper (1957b) that Si repressed Mn toxicity symptoms, but had no effect on the Mn content of the leaf tissue; however B toxicity symptoms were only slightly suppressed by Si application.

Halais and Parish (1963) found an inverse relationship between Si and Mn concentration in sugarcane sheaths. Clements (1967) reported that Si applications resulted in a marked increase in plant Si and Ca and a marked decrease in plant Mn and in the Mn/SiO_2 ratio in sugarcane sheaths. He observed that the effects of Si slag are generally similar to those of lime except when plant Si is very low and suggested that Si is possibly irreplaceable and, therefore, perhaps essential in sugarcane. Calcium silicate was found to have no significant effect on the levels of Zn, K, Mo, S, Al or Cu in sugarcane sheaths, but did significantly increase the sheath Si and Ca levels (Clements, 1965a). Clements also reported that levels of P, Mg, Mn, B, leaf N and tissue moisture were significantly reduced by calcium silicate applications. He concluded that the increased sheath Si and decreased sheath B, Mn and Mn/SiO_2 ratio were largely responsible for the yield increases following Si applications and that the freckling and bronzing of cane leaves was probably related to an imbalance of the micronutrients.

Many Japanese workers have found that Si application reduces "Akiochi" disease (rice blast disease). They have concluded that Si is deposited near the epidermis of the leaves and stems and thus acts as a protective shield against fungal diseases and insect pests. Ota et al. (1957) studied the influence of different N and Si levels on the growth and composition of rice and reported that in the presence of high N, slag applications reduced early growth and accelerated later growth while with lower N levels, slag applications had no effect on growth. They postulated that the observed effects of N and Si applications were due to Si causing the plants to become rigid and resist attack by blast disease or stem borer. They also postulated that at high N levels the high asparagine content of the leaves was causing the rice plants to be more susceptible to diseases, and Si application increased the ammonium absorption capacity of the soil.

Soil Phosphorus

One of the major problems in Hawaiian agriculture is P deficiency in plants. This problem is largely due to high fixation of P by Fe and Al oxides in Hawaiian soils. Chu and Sherman (1952) found that in soils dominated by these oxides more than 90 percent of the added P was fixed in 24 hours while only 30 percent of the applied P was fixed when the oxides were removed. Phosphorus fixation also depends on soil pH as indicated by Scarseth (1935) who reported that at low pH, P is fixed by Fe and Al oxides while at high pH, P is fixed as calcium phosphate. He also emphasized the fact that soil P solubility was related to anion exchange and observed that in certain soils the supply of P can be enhanced by replacing P from the soil with other anions, especially silicate.

Low and Black (1950) accounted for P fixation by kaolinite with the hypothesis that the clay dissociates into Si and Al ions in accordance to the solubility product principle so that when Si is applied soil Al reacts with the excess Si leaving P free to be taken up by plants.

Terman and Stanford (1960) postulated that P fertilizer added to soil first dissolves and forms a localized concentration of P, which in turn causes other soil constituents to be solubilized. The soluble constituents, especially Fe, Al and Ca, then combine with P to form relatively insoluble phosphates. Teranishi (1968) found that application of P fertilizers results in increased Si uptake by sugarcane.

Plant Phosphorus

Phosphorus is present in the plant as orthophosphate and is an essential part of many enzymes and nucleic acids (Russell, 1961). It is well documented that P is translocated from older portions of the plant to areas with high metabolic activity (Russell, 1949; Stout and Hoagland, 1940; Arnon, 1952). Clements (1968) recommended that P fertilizer should be applied to sugarcane if the amplified P index of the cane plant falls below 2400.

Teranishi (1968) found that P of the sugarcane plant increased with increasing P application. At low P levels Si application caused increased sheath P while high levels of applied Si caused decreased sheath P and P uptake. He suggested that competition between Si and P at the soil-root interface or within the plant was more important than the Si-P anion exchange effect.

Soil Acidity

In general soil reaction plays an important part in the availability of soil nutrients and optimum soil pH is a compromise between availability of some elements and toxicity of other elements (Buckman and Brady, 1965). In Hawaii, as in most of the world, a soil pH of 6-7 is usually optimum for growth of the common crop plants. Clements (1968) reported that if possible, a soil should be limed to pH 5.8 to prevent problems with ferrous iron and Mn toxicities.

Dias (1965) found that Al and Mn toxicities rather than Ca deficiency were the major problems in soils with pH levels near 5.0.

Soil and Plant Aluminum

The amount of Al present in the soil is highly dependent on soil reaction. Magistad (1925) found that between pH 5 and 7 soluble soil Al was practically absent while below pH 5 and above pH 7 Al solubilities increased rapidly. He concluded that between pH 5 and 7 the only benefit from liming was due to a decrease in acidity and not a decrease of soluble Al present. Aluminum, however, does not have to be present in the bulk soil solution to be toxic. The environment of the plant root is usually an acid one. Ligon and Pierre (1932) found that Al present in nutrient solution at concentrations higher than 1 ppm caused injury to corn, sorghum and barley and concluded that plants grown in soils of less than pH 5.0 may be seriously injured by Al. Although Teranishi (1968) found no statistically significant differences in KCl-extractable soil Al due to Si, P or pH treatments he did find that Al solubility, generally, was greater under the more acid conditions. He also found that Si applications decreased extractable soil Al

Taylor et al. (1965) found that the addition of gibbsite to ammonium phosphate solutions with low pH caused ammonium taranakite to precipitate out while iron oxides reacted only slightly with ammonium phosphate at any pH.

Lipman (1938) found that yields of sunflower and corn in solution culture benefit by the presence of some Al. Randall and Vose (1963) and Medappa and Dana (1968) found increasing P uptake as Al increased to about 1.2 ppm in culture solutions and then decreased after about 12 ppm. Randall and Vose (1963) studied this effect and observed that metabolic inhibitors reduced the Al-induced P uptake and concluded that the Al-induced P uptake is a metabolic process; however, they could not rule out precipitation effects on root surfaces.

MATERIALS AND METHODS

Description of Soil

The experiment was installed on Halii soil classified by Ikawa and Sato (unpublished, 1969) as a gibbsihumox. They described the upper horizon of the Halii series as follows:

> Ap -- 0-32 cm -- Dark brown (10YR 3/3) gravelly silt loam; strong medium, fine and very fine granular structure; friable, slightly sticky, slightly plastic; no roots; many fine pores; many fine and medium iron concretions; few saprolyte fragments from lower horizons; abrupt wavy boundary.

Halii soils are characterized by many small, smooth surfaced, concretions which contain up to 65% Fe_2O_3 and 10-20% Al_2O_3 (Sherman, 1968). The parent material is basalt. Dominant vegetation of the area includes Ohia lehua (*Metrosideros* sp.), koa (*Acacia koa*, Gray), guava (*Psidium guajava*, L.), and false staghorn fern (*Sicranopteris* sp.). Where these species have been cleared, Hilograss (*Paspalum conjugatum*, Bergius), yellow foxtail (*Setaria geniculata* (Lam.) Beauv.), and rice grass (*Paspalum orbiculare*, Forst) are common as well as kikuyu grass (*Pennisetum clandestinum*, Hochst) which is one of the best introduced species.

The concentrations of various nutrients in this soil were determined in the control plot which received only the blanket application of N, K, Zn, Mg, B and Mo (Table 1). Samples were taken at 4, 9 and 18 months after the cane was planted.

Table 1. Concentration of Nutrients in the Control Plot After Harvesting a Plant and Ratoon Crop of Sugarcane

Element	Date (Months after planting) 9	18
Si (1:10 water extractable, ppm Si in solution)	0.48	0.50
P (modified Truog, ppm P)	9	13
K (exchangeable, ppm K)	----	46
Ca (exchangeable, ppm Ca)	----	110
Mg (exchangeable, ppm Mg)	----	19.1
Al (N KCl extractable)	----	49.0
Soil pH	4.8	5.3

Experimental Methods

Three replications of a 3^3 factorial experiment in a split-plot design were laid out on a 0.6 ha field at the Kauai Branch Station (HAES) by Dennis Y. Teranishi in November 1966. Whole plots were three pH treatments (pH 5.5, 6.0 and 7.0) and the subplots were factorial combinations of 3 P treatments (112, 280 and 1120 kg P/ha) and 3 Si treatments (0, 833, 1666 kg Si/ha). A blanket application of N, K, Mg, Zn, B and Mo was applied over the field. Nutrient sources and application rates are shown in Table 2. Titration curves for both Si slag (TVA slag) and lime were used to determine amounts of lime or elemental S required to adjust the soil pH to 5.5, 6.0 and 7.0.

Supplementary plots were included in the experiment to study the effects of increasing Si (0, 833, 1666 kg Si/ha) at zero P (pH 6.0) and increasing P (112, 280, 1120 kg P/ha) at the original field pH (pH 5.0). A no treatment plot was also included in the experiment. These plots were adjacent to the main factorial experiment and were not included in the analysis of variance for the split-plot experiment.

Cultural Practices

The subplots were 6.1 x 9.1 meters and the whole plots were 18.3 x 27.4 meters. After the field was plowed the blanket fertilizer was applied and the differential fertilizer treatments were

Table 2. Rates and Sources of Nutrients
Added to the Halii Soil Before Planting Sugarcane

Element	Rate of Application (kg/ha)	Source
N	112*	Urea (46% N)
P	112 280 1120	Treble Super Phosphate (20% P)
K	224	Potassium Chloride (61% K)
Ca	As Required	Agricultural Lime (31% Ca)
Mg	21.5	Magnesium Sulfate (9.6% Mg)
Zn	56	Zinc Sulfate (36% Zn)
S	As Required	Elemental Sulfur
B	2.37	Sodium Borate (10.6% B)
Mo	0.44	Sodium Molybdate (39% Mo)
Si	0 833 1666	TVA Calcium Silicate-Slag (18.6% Si)

*2 similar applications of N were made in March and June. A third application of N was made when the crop was ratooned.

broadcast by hand. The field was disc with a disc harrow to mix the soil and fertilizers.

Sugarcane, variety H53-263, was planted on November 21, 1966. Ten rows, each 0.91 meters apart, were planted in each plot. This spacing was used since the cane was to be harvested after 9 months. Irrigation was not necessary as the local annual rainfall of 210-240 cm was well distributed throughout the year. Weeds were controlled by use of a contact herbicide until the cane closed in. Nitrogen was reapplied in March and June at the rate of 112 kg per hectare.

On August 10, 1967, the sugarcane was harvested and ratooned. The ratoon crop received 112 kg N/ha; weeds were again controlled by use of a contact herbicide. Monthly rainfall during the 9-month growing period of the ratoon crop is shown in Table 3.

Plant Sampling

Sheath samples were collected according to the method of Clements (1957) when the ratoon crop was 6, 8 and 9 months old. Two stalks were collected from the third and eighth rows of every plot and the sheaths of leaves 3, 4, 5 and 6, counting the spindle as leaf number one, were removed. The fresh weight of the 16 sheaths was recorded and the sheaths were chopped into centimeter-long sections, thoroughly mixed and 10

Table 3. Rainfall Distribution During the Growing Period of the Ratoon Sugarcane Crop

Month	Rainfall (cm)
August (10-30)	9.83
September	13.06
October	15.16
November	27.94
December	41.50
January	19.02
February	9.09
March	26.92
April	28.09
May	5.31
June (1-17)	3.78
Total	199.70

and 100 g subsamples taken for analysis of TCA soluble sheath Si and for moisture determination and subsequent chemical analysis. The samples were dried at 70°C, weighed for moisture determinations and ground in a Wiley mill to pass a 20 mesh sieve.

Soil Sampling

Soil samples were collected by Teranishi when the plant crop was 4 months old and immediately after harvest (9 months). Soil samples were also collected after harvest of the ratoon crop. Samples consisted of four cores of surface soil (0-15 cm) from each plot. These cores were mixed thoroughly and a subsample stored in a polyethylene plastic bag for analysis. Before analysis the samples were passed through a 9 mesh sieve to break up clods and remove rocks and debris.

Harvest

The ratoon crop of sugarcane was harvested at 10 months of age (17 June 1968). To minimize border effects plants were discarded from the four outside rows and 1.52 meters on either end of the plot. This left a harvest area of 3.05 x 5.49 meters (0.001674 ha) per plot.

Plants were hand cut at ground level and weighed. Ten stalks were selected at random, weighed, chopped with a mechanical chopper and a 200 g subsample was taken for moisture determination and subsequent chemical analysis. Samples were dried at 70°C in a forced air oven, moisture content determined, and ground to less than 20 mesh in a Wiley mill.

Analytical Methods

Plant Analysis

The concentrations of Si, N, P, K, Ca, Mg, Mn and Al were determined in the plant materials. For detailed methods of extraction and analysis see Appendix A.

TCA Extractable Silicon: TCA soluble Si in cane sheaths was extracted by the method of Fox *et al*. (1967) immediately after collection of the sheath samples. Silicon was determined by the Silico-Molybdate method described by Kilmer (1965).

Total Silicon: Total Si was determined on a solution prepared by fusion of an ashed sample with lithium tetraborate according to the method of Suhr and Ingamells (1966). Silicon was determined by the Silico-Molybdate Blue method of Kilmer (1965).

Wet Ashing: A second portion of the ground plant material was digested in a 2:1 nitric:perchloric acid mixture. This digest was used for the determination of P, K, Ca, Mg, Mn and Al.

Plant Phosphorus: An aliquot of the perchloric digest was analyzed for P by the Vandate-Molybdate Yellow method of Barton (1948).

Plant Calcium and Magnesium: An aliquot of the nitric-perchloric digest was combined with lanthanum oxide solution and diluted tenfold so that the digest contained 0.3 percent lanthanum. The lanthanum was added to eliminate interferences from aluminum, phosphate and sulfate ions. Plant Ca and Mg were determined with a Perkin-Elmer atomic absorption spectrophotometer.

Plant Potassium: The solution used for Ca determination was used for K analysis on the Beckman DU flame photometer.

Plant Manganese and Aluminum: Plant Mn and Al were determined directly on a portion of the nitric-perchloric digest solution with a Perkin-Elmer atomic absorption spectrophotometer.

Total Plant Nitrogen: Total plant N of the whole plant sample was determined by the Kjeldahl method.

Soil Analysis

Soil pH, extractable Si, P, Al and exchangeable K, Ca and Mg were determined on the soil samples collected after the ratoon crop of sugarcane was harvested. The complete methods of extraction and analysis are given in Appendix A.

Soil pH: Soil pH was determined on a 1:2.5 soil:water suspension using a 10 g sample of field-moist soil. The pH was read on a Beckman Model N glass electrode pH meter following a 30 minute equilibration period.

Soil Silicon: Soil Si was extracted with water and also with the modified Truog extracting solution (0.02 N sulfuric acid). Silicon in both extractants was determined by the Silico-Molybdate Blue method.

Soil Phosphorus: Soil P was extracted by the modified Truog method of Ayres and Hagihara (1952) and determined by the Molybdate Blue method of Dickman and Bray (1940).

Soil Potassium and Soil Magnesium: Soil K and Mg were extracted with N ammonium acetate, pH 7.0, and determined directly on a Perkin-Elmer atomic absorption spectrophotometer.

Soil Calcium: Exchangeable soil Ca was determined on the same extract used for soil K analysis. Before determining Ca on the atomic absorption spectrophotometer an aliquot of the solution was combined with lanthanum oxide solution and diluted 16.7 times so that the extract contained 0.5 percent lanthanum.

Soil Aluminum: Exchangeable soil Al was extracted with N potassium chloride solution and determined by the Aluminon method of Chenery (1948).

RESULTS AND DISCUSSION

Yield results and plant and soil data are discussed in the following order - yield, Si, P, pH, N, K, Ca, Mg, Mn and Al. In each of these sections first soil and then plant factors are presented in detail. A general discussion of the various interrelationships is presented with regression analysis in the last section.

Yield

Yields of the ratoon sugarcane crop were not significantly affected by the Si, P or pH treatments according to an analysis of variance (Table 4). However, yields tended to increase as the amount of residual Si increased (Figure 1) and the mean yields for the 1666 kg Si per hectare plots and 0 Si plots were shown to be significantly different by the Duncan's multiple range test. The Duncan's multiple range test determines significant differences between means while the F test determines the average treatment effects. Effects of residual P were not statistically significant, but inspection of Figure 1 shows that the high (1120 kg) P treatment out-yielded the low (112 kg) P treatment by 4 tons (metric) per hectare at the zero Si level and 6.4 tons (metric) per hectare of the high (1666 kg) Si level. The marked decrease in yield of the high (1120 kg) P treatment which occurred at the medium (833 kg) Si level is difficult to explain

Table 4. Analysis of Variance of Ratoon Crop Cane Yields

Source of Variation	df	Mean Squares
Whole Plots:		
Replications	2	2041.98
pH	2	775.71
Error (a)	4	728.75
Subplots:		
Si	2	1360.62
P	2	145.62
Si x P	4	86.49
Si x pH	4	1054.38
P x pH	4	226.82
Si x P x pH	8	419.74
Error (b)	48	504.10

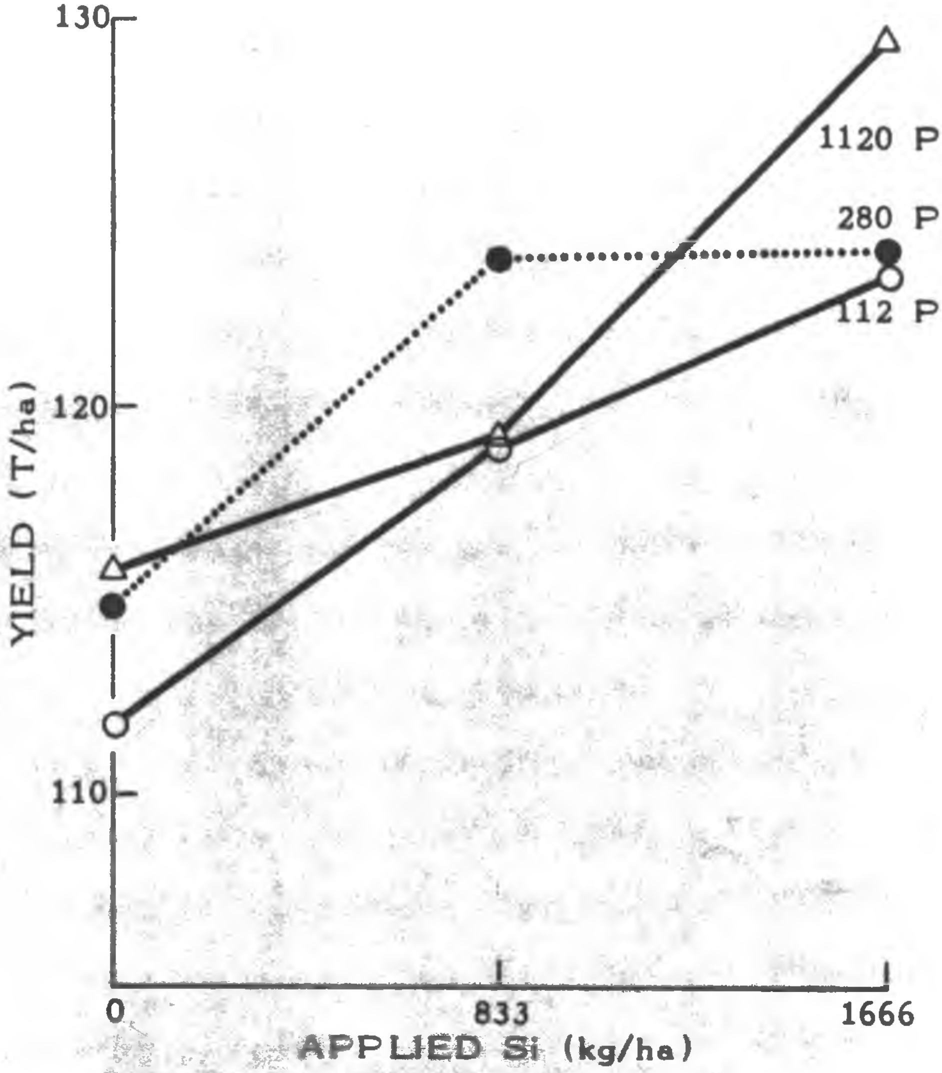

Figure 1. Influence of Residual Si and P on Yield of Sugarcane (Ratoon Crop) Harvested at Nine Months.

especially since the yields of the medium (280 kg) P treatments exceeded those of the low (112 kg) P treatment by 4.8 tons per hectare at this Si level. One possible reason for this decreased yield of the high P treatment is that the plant crop depleted one or more essential nutrients in this treatment so growth was limited. This P and Si combination produced the highest yields in the plant crop. Certain plots of the experiment were damaged by rats but no correlation with treatment was observed. More on this subject will be presented as the individual elements are discussed.

Green sheath weight was found to be significantly affected by residual P at four and eight months but not at nine months (Table 5). The fact that P normally has its greatest effect on growth early in the crop may explain the observed results. At four months, the green sheath weight first increased and then decreased sharply with increasing P rates (Figure 2). This pattern may be the result of nutrient deficiencies brought about by the large quantities harvested in the plant crop. This effect may intensify with increasing age, thus accounting for the diminishing response to residual P at eight and nine months.

Silicon

Soil Silicon. Analysis of variance of water extractable Si showed a highly significant effect of Si on yield and a significant

Table 5. Analysis of Variance of Sugarcane Green Sheath Weights Sampled at Four, Eight, and Nine Months

Source of Variation	df	Age in Months		
		4	8	9
			mean squares	
Whole Plots:				
Replications	2	2251.59*	2360.23	769.12
pH	2	71.81	708.79	1223.79
Error (a)	4	187.18	1439.75	1211.12
Subplots:				
Si	2	211.15	803.49	168.98
P	2	2149.78*	2171.60*	850.98
Si x P	4	305.59	485.60	871.94
Si x pH	4	1703.74*	972.40	1729.53
P x pH	4	88.15	920.01	219.14
Si x P x pH	8	483.27	914.96	275.69
Error (b)	48	580.43	598.52	915.11

*Significant at the 5% level.

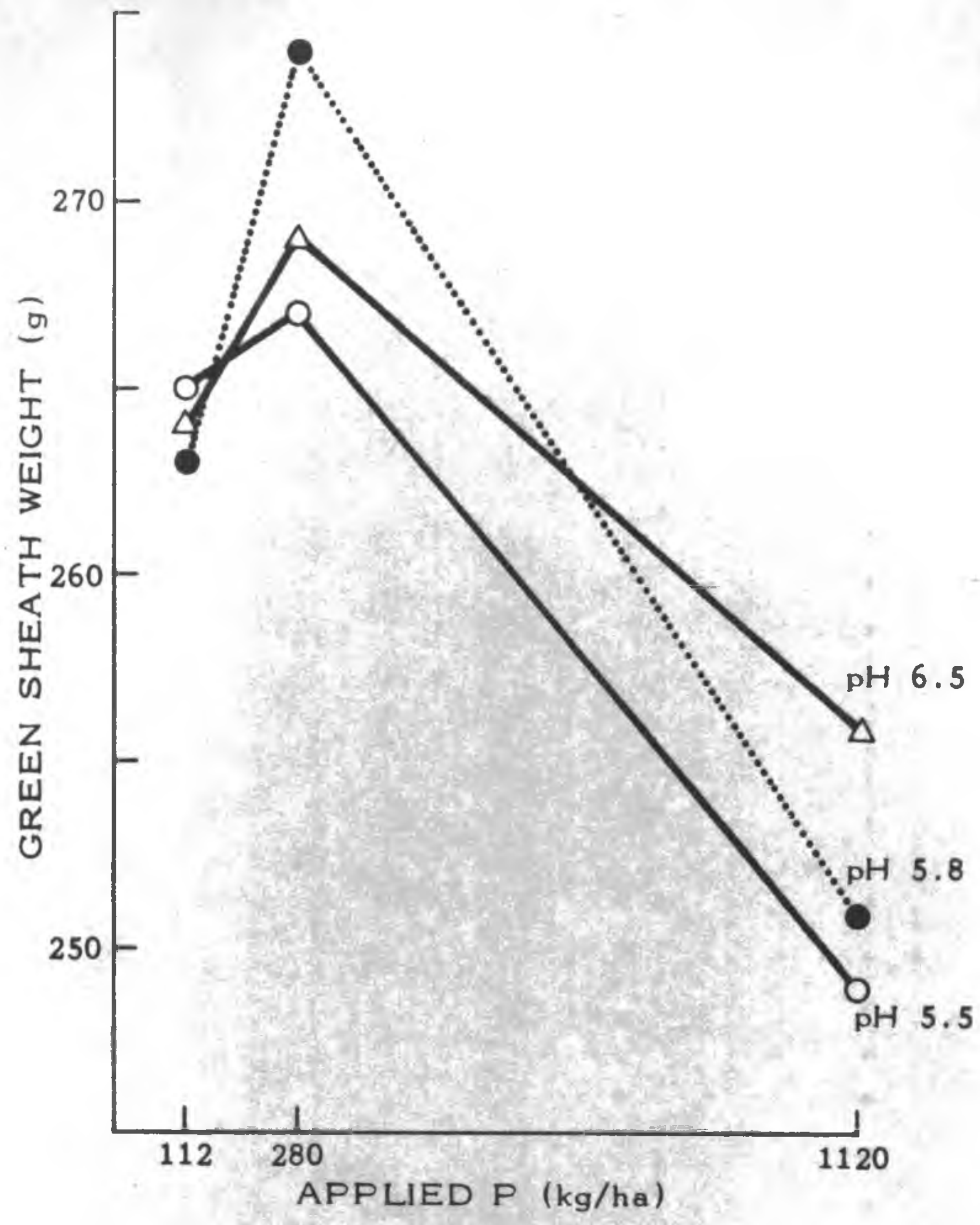

Figure 2. Influence of Residual Si and Soil pH on Sugarcane Green Sheath Weights (4-Month Sample).

Si x pH interaction (Table 6). This interaction is illustrated in Figure 3 in which water extractable soil Si increased linearly with residual Si and decreased with increasing soil pH. Analysis of variance of modified Truog extractable Si showed highly significant Si and pH effects and also a highly significant Si x pH interaction. This Si x pH interaction is illustrated in Figure 4 in which extractable Si increased with residual Si and soil pH It should be noted that both water extractable and modified Truog extractable soil Si increased linearly with increasing residual Si, however modified Truog extractable Si increased with increasing pH while water extractable Si decreased with increasing pH. This reversal may be due to the effects of actual soil pH on Si solubility in water extraction while in modified Truog extraction, the 2.2 pH extracting solution masked the actual soil pH differential. Thus, the actual amounts of Si remaining in the soil from the Si treatments was measured by the modified Truog extraction and those pH levels which originally had high Si uptake and leaching in the plant crop had low amounts of Si extracted by the modified Truog extractant. Both water and modified Truog extractable Si levels were at or near the deficiency levels of 0.9 and 50 ppm, respectively, set by Fox et al. (1967) Even the 833 and 1666 kg Si treatments were in the deficiency questionable range, with the exception of the 1666 kg Si treatment at pH 5.5.

Table 6. Analysis of Variance of Water-Extractable and Modified Truog-Extractable Soil Si

Source of Variation	df	Water	Modified Truog
		mean squares	
Whole Plots:			
Replications	2	0.172	1718
pH	2	1.447	22332**
Error (a)	4	0.279	265
Subplots:			
Si	2	11.690**	118217**
P	2	0.025	718
Si x P	4	0.016	549
Si x pH	4	0.283*	3954**
P x pH	4	0.033	816
Si x P x pH	8	0.023	633
Error (b)	48	0.082	921

*Significant at the 5% level.
**Significant at the 1% level.

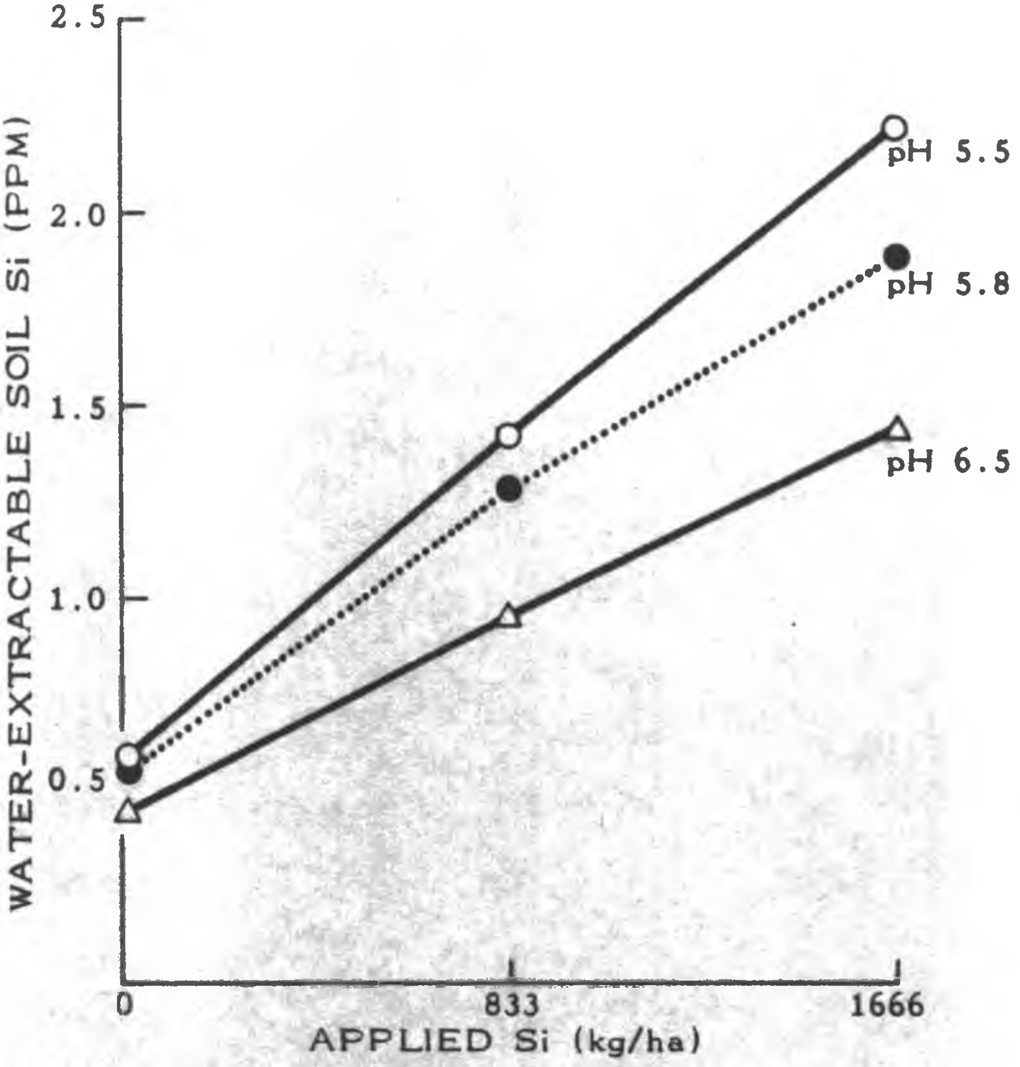

Figure 3. Influence of Residual Si and Soil pH on 1:10 Water-Extractable Soil Si.

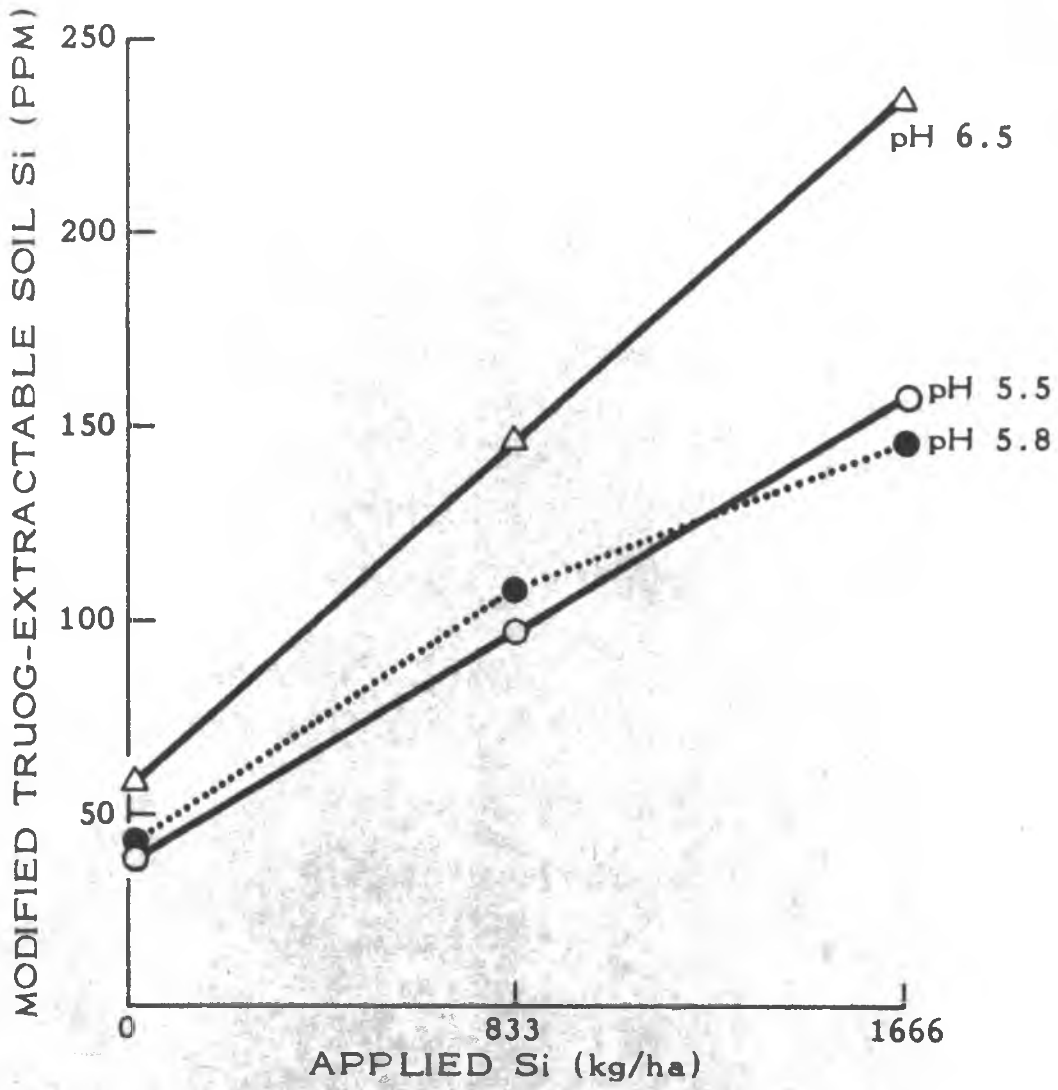

Figure 4. Influence of Residual Si and Soil pH on Modified Truog-Extractable Soil Si.

Increasing soil P did not increase extractable soil Si as was reported for the same plots earlier by Teranishi (1968). Thus P effects must be a short-term mass action effect on Si and persist only as long as P additions continue to increase P in solution significantly.

Plant Silicon. Residual Si had a significant effect on TCA extractable sheath Si at all three ages while the Si x pH and P x pH interactions were significant at nine months only (Table 7). The Si x pH interaction is illustrated in Figure 5 in which TCA extractable Si increased with residual Si and decreased with soil pH. TCA extractable Si appears to be better related to water extractable soil Si than to modified Truog extractable Si.

Sheath Si at eight and nine months and also whole plant Si decreased significantly as pH increased while sheath Si at all three ages and total plant Si increased significantly as residual Si increased. The Si x pH and P x pH interactions were also significant at most sampling ages (Table 8). The low Si treatments and the medium Si treatments at pH 6.5 were at deficiency levels while the other medium and high Si treatments were in the deficiency questionable range except at pH 5.5. The effects of various factors on sheath Si increased with age as indicated by the increasing levels of significance for pH as well as for the Si and P interactions with pH. These effects of Si with age are similar to those reported by Adlan (1969). The Si x pH

Table 7. Analysis of Variance of TCA-Extractable Si in Sheaths Sampled at Four, Eight, and Nine Months

Source of Variation	df	Age in Months		
		4	8	9
			mean squares	
Whole Plots:				
Replications	2	298.0	13.7	1140.6
pH	2	66.9	326.1	727.4
Error (a)	4	46.2	86.4	177.0
Subplots:				
Si	2	2237.2**	2925.8**	1507.8**
P	2	16.2	58.8	7.9
Si x P	4	40.3	118.7	40.0
Si x pH	4	35.7	32.7	166.2**
P x pH	4	20.6	62.1	147.4*
Si x P x pH	8	21.0	70.1	19.5
Error (b)	48	31.6	68.1	42.0

*Significant at the 5% level.
**Significant at the 1% level.

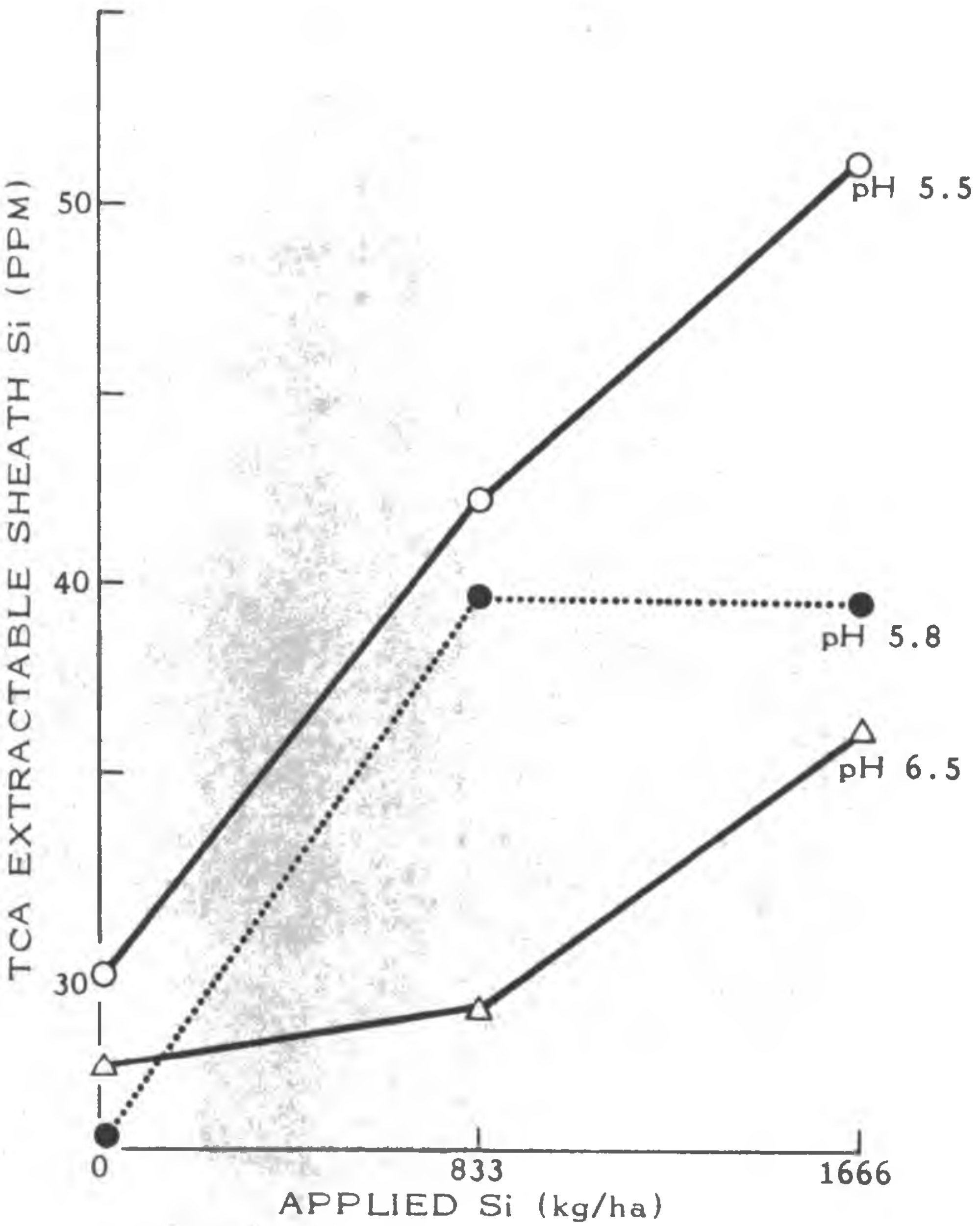

Fig. 5. Influence of Residual Si and Soil pH on TCA Extractable Sheath Si (Nine-Month Sample).

Table 8. Analysis of Variance of Sheath Si at Four, Eight and Nine Months and Whole Plant Si at Nine Months

Source of Variation	df	Sheath Si (Age in Months)			Whole Plant Si
		4	8	9	
		mean squares			
Whole Plots:					
Replications	2	583680	183258	612	124173
pH	2	1725838	3056997*	2712052**	4203312**
Error (a)	4	264370	388598	109706	88927
Subplots:					
Si	2	94573508**	74622438**	43974966**	26531670**
P	2	260388	1033624	191560	425623
Si x P	4	1002340	1100113	166399	281279
Si x pH	4	1560109	1844012*	1252947**	1606331**
P x pH	4	1356004	410350	838460*	503723*
Si x P x pH	8	202205	887805	272449	193981
Error (b)	48	815462	679974	306691	186713

*Significant at the 5% level.
**Significant at the 1% level.

interactions in the sheath (nine-month sample) and the whole plant samples are illustrated in Figures 6 and 7, respectively. These curves follow essentially the same pattern, i.e., increasing plant Si with increasing residual Si and decreasing pH, with the exception of sheath Si in the 833 kg Si level at pH 5.8 (Figure 6) Duncan's multiple range test indicated that the sheath Si means for pH 5.5 and 5.8 were not significantly different from each other, but were significantly higher than the pH 6.5 mean. Whole plant Si and sheath Si were found to be highly correlated (r = 0.711, 0.755, and 0.787 for four, eight and nine months, respectively). The sheath Si levels at nine months were all below the tentatively established critical levels of 5000 ppm except for the high Si treatment which was in the deficiency questionable range. This does not agree with the other measurements of Si and reasons for the discrepancy are not apparent.

As in the case of water extractable soil Si, sheath and whole plant Si increase with increasing applied Si and decrease with increasing soil pH. Figure 8 illustrates the relationship between water extractable soil Si and sheath Si (nine months) in which sheath Si is the dependent variable and soil Si the independent variable (r = 0.82). These data confirm the observations of Fox _et al_. (1967), Teranishi (1968) and many others who found that plant Si increases directly with soil Si.

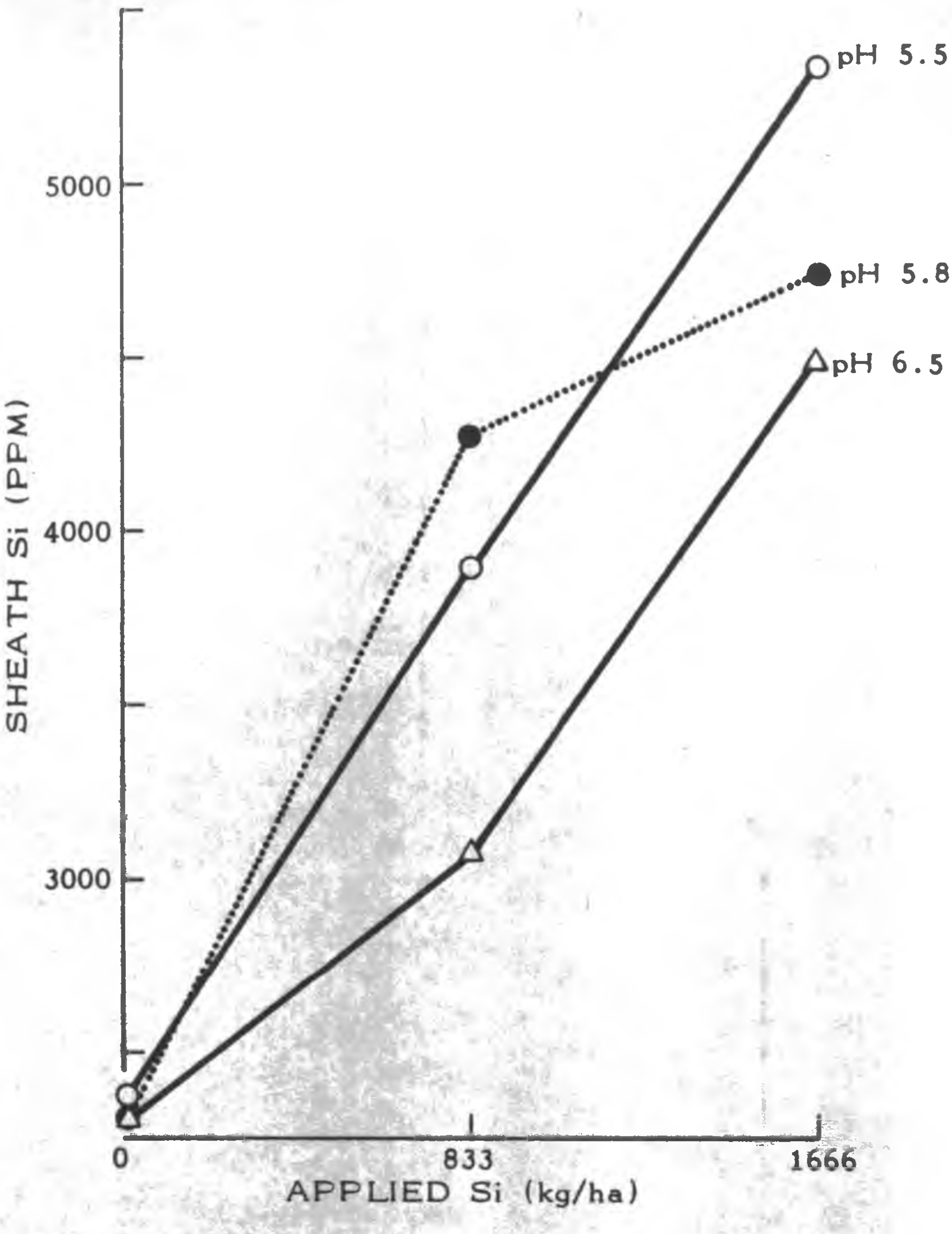

Figure 6. Influence of Residual Si and Soil pH on Sheath Si (Nine-Month Sample).

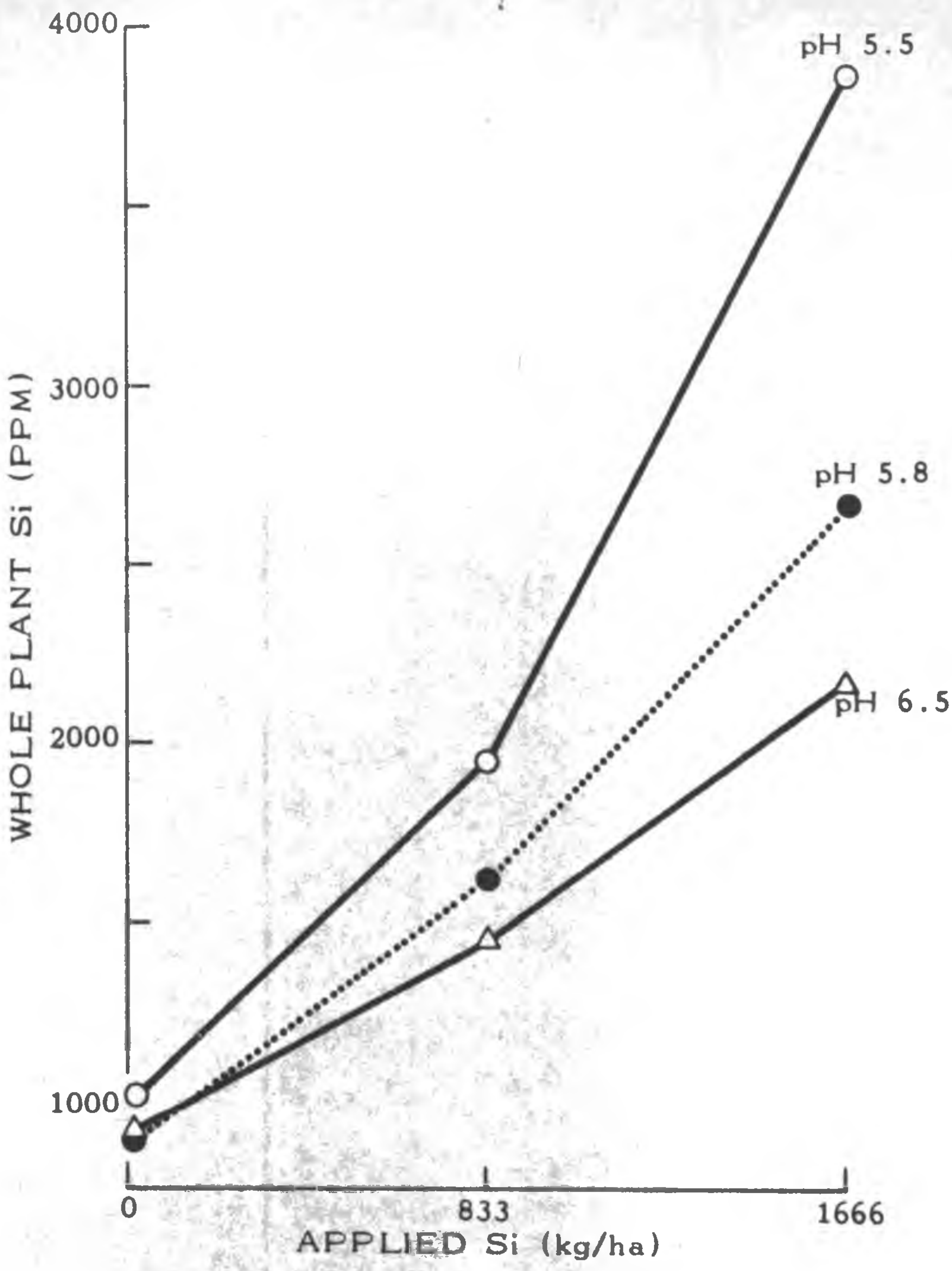

Figure 7. Influence of Residual Si and Soil pH on Whole Plant Si.

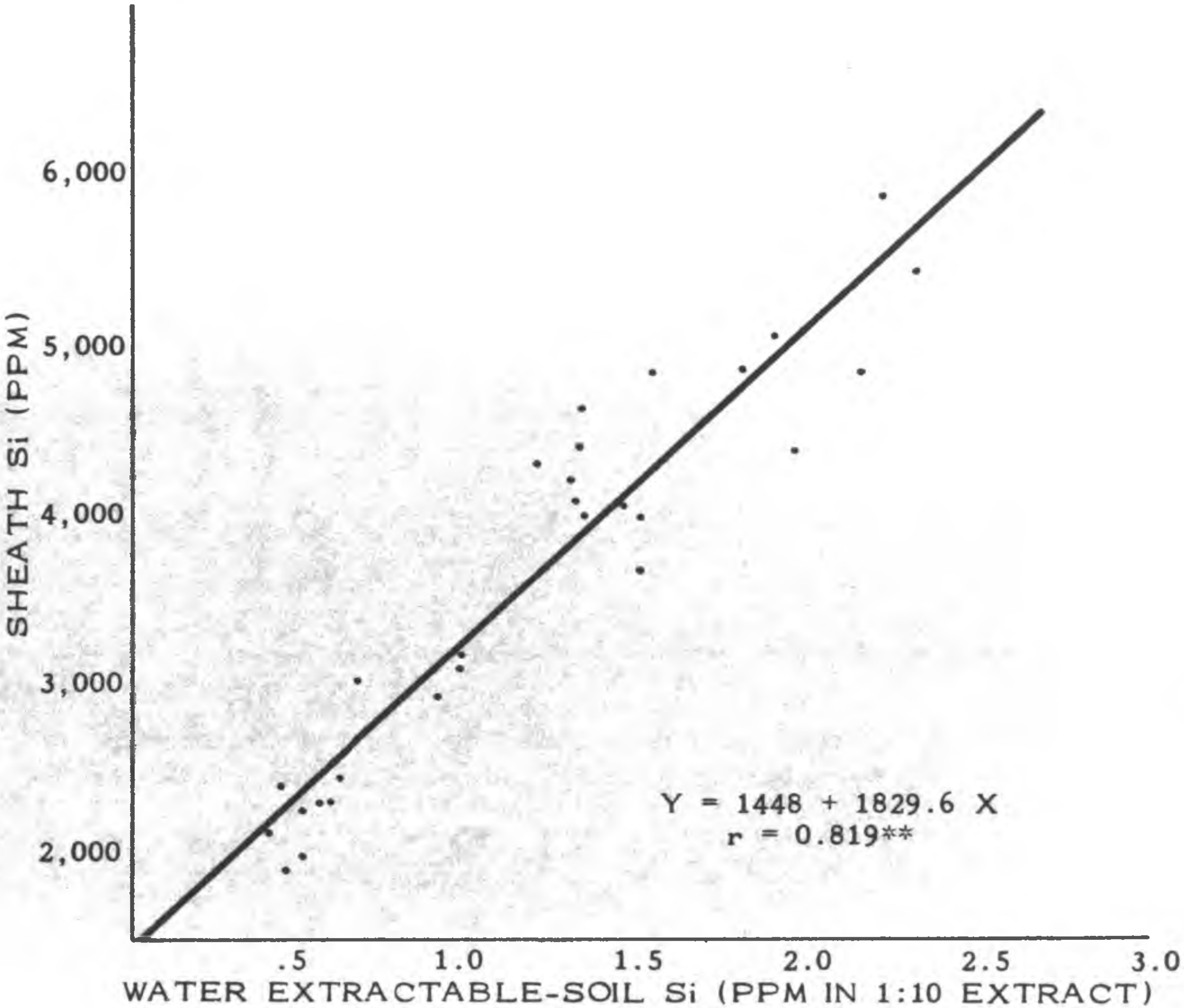

Figure 8. Relationship Between Water-Extractable Soil Si and Sheath Si in Sugarcane (Nine-Month Sample).

Silicon uptake followed essentially the same pattern as whole plant Si (Table 9, Figure 9). The effects of yield on Si uptake are quite small because Si applications had a relatively small effect on yield, but a relatively large effect on plant Si concentrations. When the combined Si uptake of the plant and ratoon crops are considered (Table 9) the effects of applied Si were highly significant. Figure 9 illustrates the Si x pH interaction in Si uptake by the ratoon crop. Silicon uptake at pH 5.5 was found to be significantly higher than that at pH 5.8 or 6.5 by Duncan's multiple range test. It should be noted that the average Si uptake of the ratoon crop was 48.8 percent of the combined uptake of the two crops which seems to indicate that Si availability remained constant during these two crop cycles. The relatively small yield increase from residual Si application in the ratoon crop was probably due to some other limiting factor, possibly N, K or Mg.

Phosphorus

Soil Phosphorus. The increase in modified Truog extractable soil P with residual P application was large and highly significant (Table 10, Figure 10). The effect of Si application on the amount of extractable P was relatively small, but analysis by Duncan's multiple range test showed that significantly more P was extracted from soil receiving high Si than from soil receiving no Si. Teranishi (1968) found a greater effect of applied Si on soil

Table 9. Analysis of Variance of Si Uptake by the Ratoon Crop and of the Combined Si Uptake by the Plant and Ratoon Crops

Source of Variation	df	Si Uptake	Combined Si Uptake
		mean squares	
Whole Plots:			
Replications	2	32	260
pH	2	3703**	4134*
Error (a)	4	91	445
Subplots:			
Si	2	30563**	102981**
P	2	363	2347*
Si x P	4	215	122
Si x pH	4	2215**	2527*
P x pH	4	200	659
Si x P x pH	8	129	137
Error (b)	48	231	702

*Significant at the 5% level.
**Significant at the 1% level.

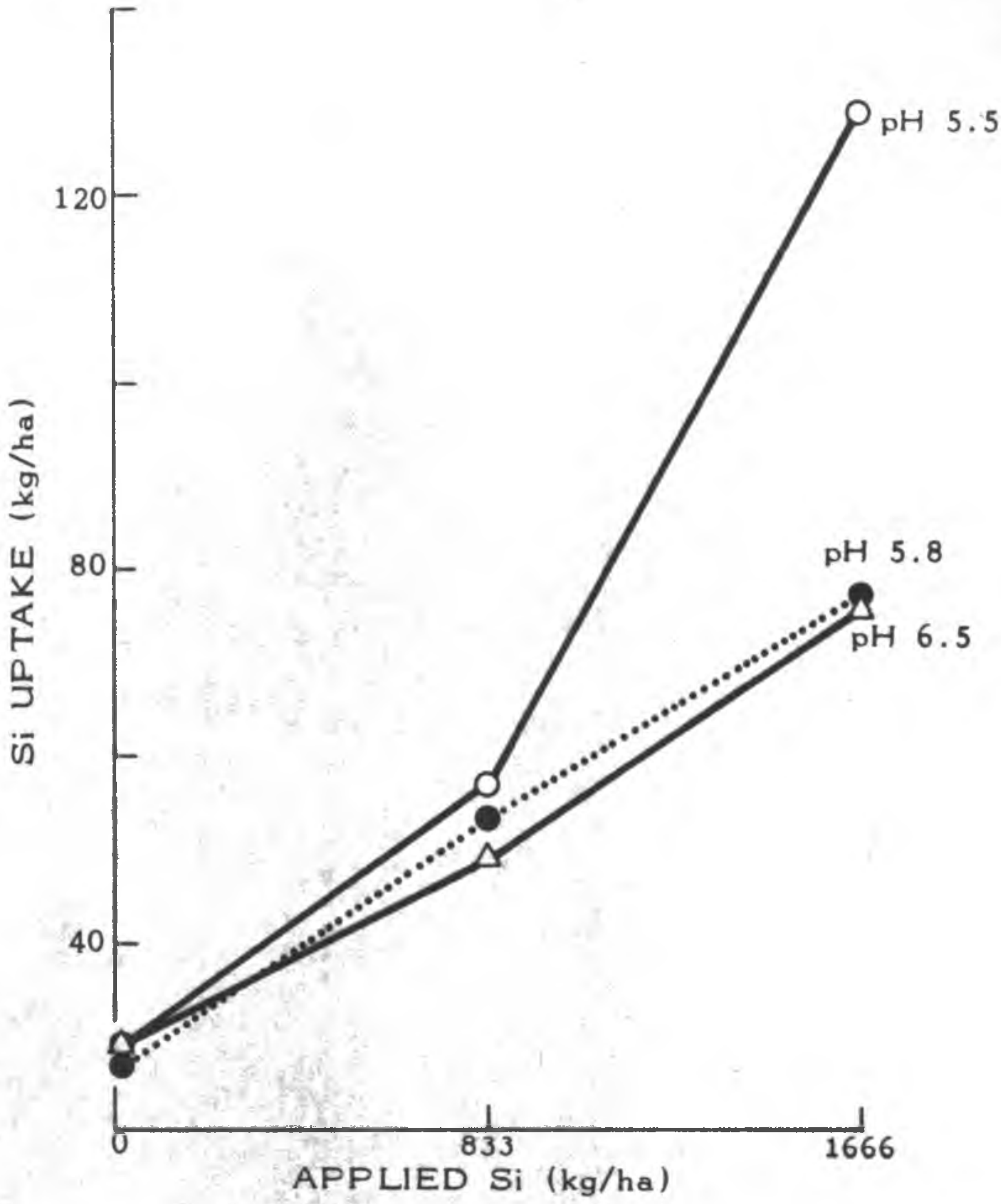

Figure 9. Influence of Residual Si and Soil pH on Si Uptake (Ratoon Crop).

Table 10. Analysis of Variance of Modified Truog-Extractable Soil P

Source of Variation	df	Mean Squares
Whole Plots:		
Replications	2	5594
pH	2	992
Error (a)	4	1205
Subplots:		
Si	2	2832
P	2	246197**
Si x P	4	863
Si x pH	4	1057
P x pH	4	109
Si x P x pH	8	2021
Error (b)	48	1220

**Significant at the 1% level.

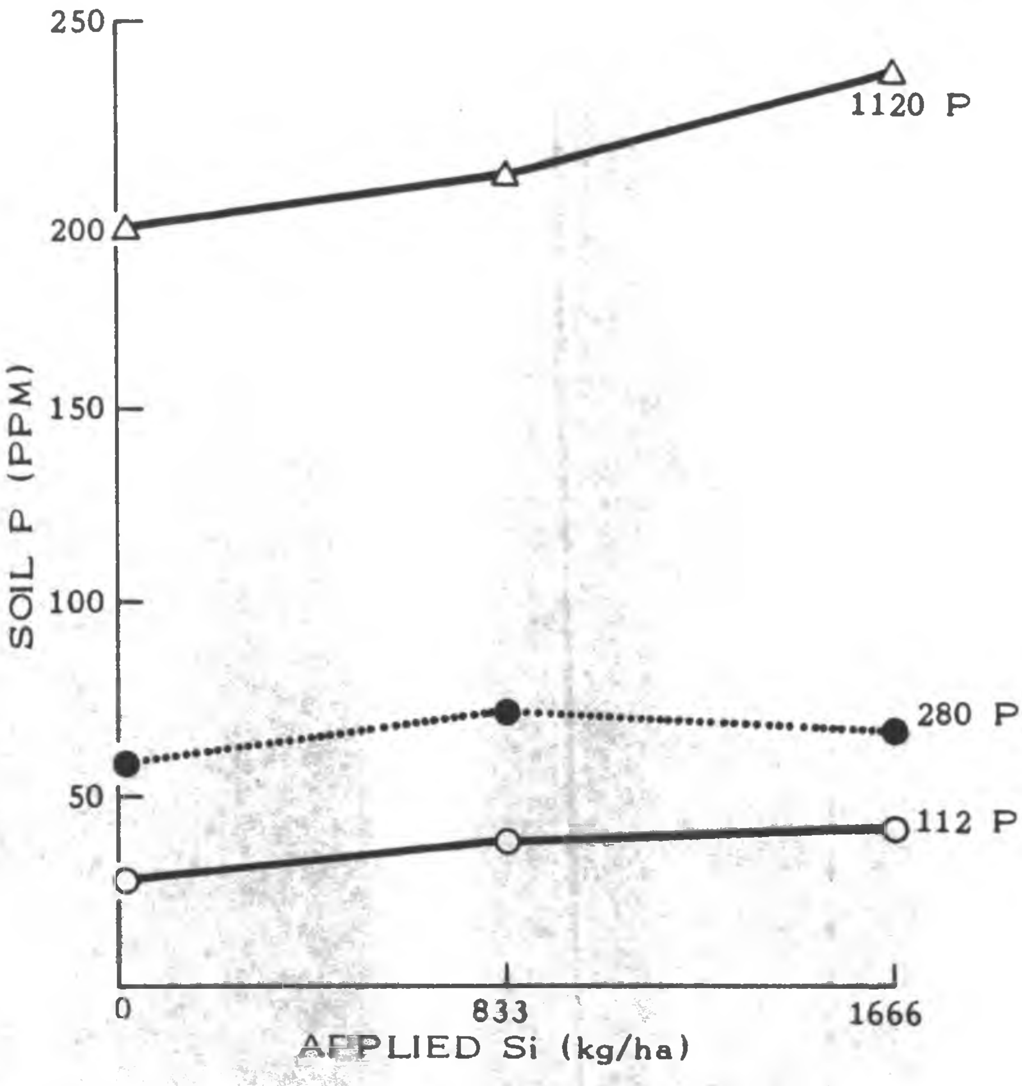

Figure 10. Influence of Residual Si and P on Modified Truog-Extractable Soil P.

P in the plant crop than was found in the ratoon crop. This agrees with Australian data of Raupach and Piper (1959) who found that the effect of silicate on phosphate solubility was temporary and lasted no longer than one year.

Teranishi (1968) reported that at higher soil P levels increasing pH decreased extractable soil P. However, in this study, and in a study by Ibrahim (1968), there was a trend for extractable P to increase with increasing soil pH. This trend, although non-significant, is at least reasonable in the light of the effect of Fe and Al solubilities on P fixation.

Plant Phosphorus. Sheath P and whole plant P were significantly increased by residual P but were not affected by residual Si or soil pH (Table 11, Figure 11). The effects of residual P and soil pH on P uptake were highly significant but that of residual Si was not significant (P = 7%) (Table 12). Analysis by Duncan's multiple range test indicated that P uptake from the high Si plots was significantly higher than that in plots not treated with Si. Sheath P levels of the low P treatments were slightly below critical levels (Humbert, 1964). Apparently, P was not limiting plant growth since even when there was an increase in yield the concentration of P in the plant remained unchanged; conversely, when yield was increased or decreased by residual Si or soil pH treatment, the changes were reflected in P uptake (Table 12, Figure 12). These results are apparent

Table 11. Analysis of Variance of Sheath P Sampled at Four, Eight, and Nine Months and Whole Plant P at Nine Months

Source of Variation	df	Sheath P (Age in Months)			Whole Plant P
		4	8	9	
		mean squares			
Whole Plots:					
Replications	2	46357	280328	36264	5523
pH	2	160286	17597	24916	17132
Error (a)	4	83312	77907	109741	9141
Subplots:					
Si	2	4981	57469	12881	889
P	2	551582**	777128**	866973**	517392**
Si x P	4	9622	14155	10889	4650
Si x pH	4	5567	11180	3061	15543
P x pH	4	5938	23018	57908	9162
Si x P x pH	8	16257	12244	16033	5062
Error (b)	48	13860	34686	24403	9991

**Significant at the 1% level.

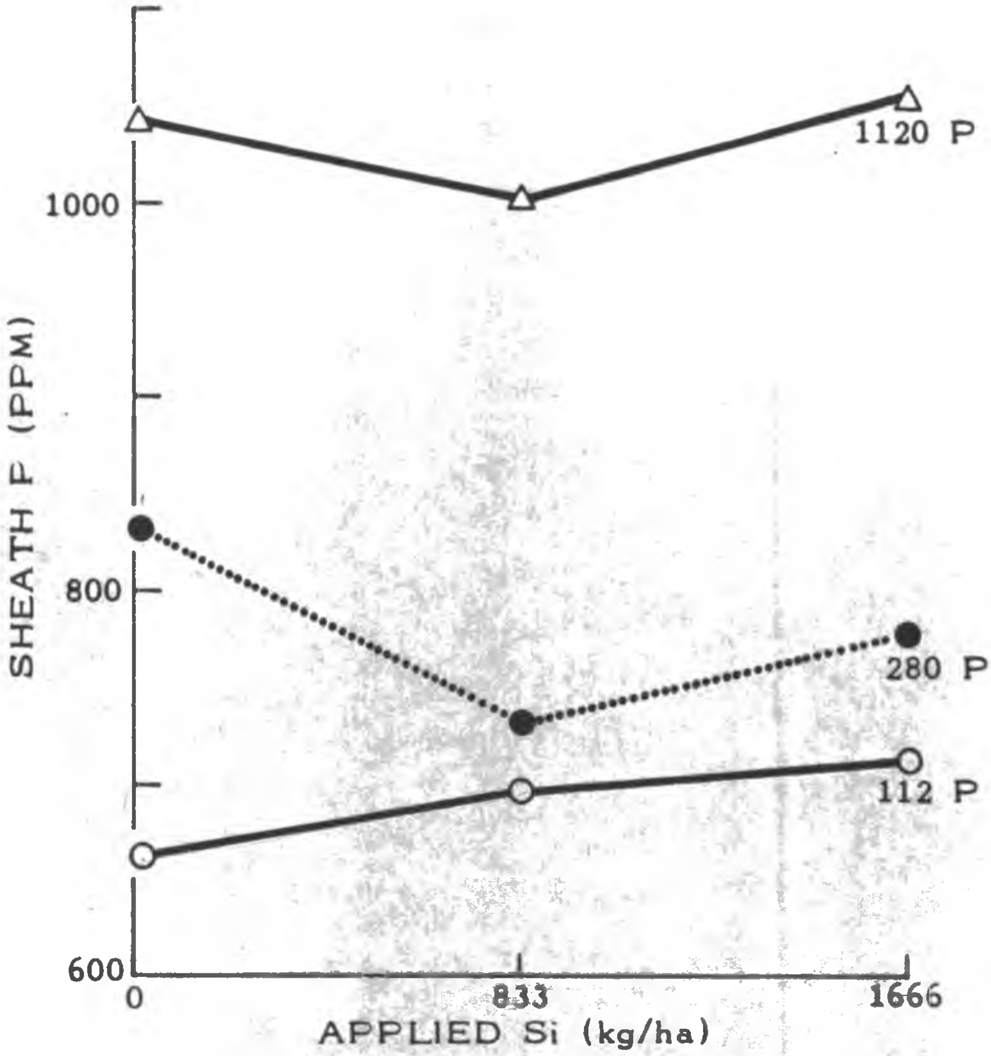

Figure 11. Influence of Residual Si and P on Sheath P (Nine-Month Sample).

Table 12. Analysis of Variance of P Uptake by the Ratoon Crop and of the Combined P Uptake by the Plant and Ratoon Crops

Source of Variation	df	P Uptake	Combined P Uptake
		mean squares	
Whole Plots:			
Replications	2	0.167	22.7
pH	2	0.804**	305.6*
Error (a)	4	0.040	38.0
Subplots:			
Si	2	0.235	123.0
P	2	5.490**	1510.1**
Si x P	4	0.037	6.2
Si x pH	4	0.068	8.7
P x pH	4	0.069	23.8
Si x P x pH	8	0.151	38.7
Error (b)	48	0.077	19.4

*Significant at the 5% level.
**Significant at the 1% level.

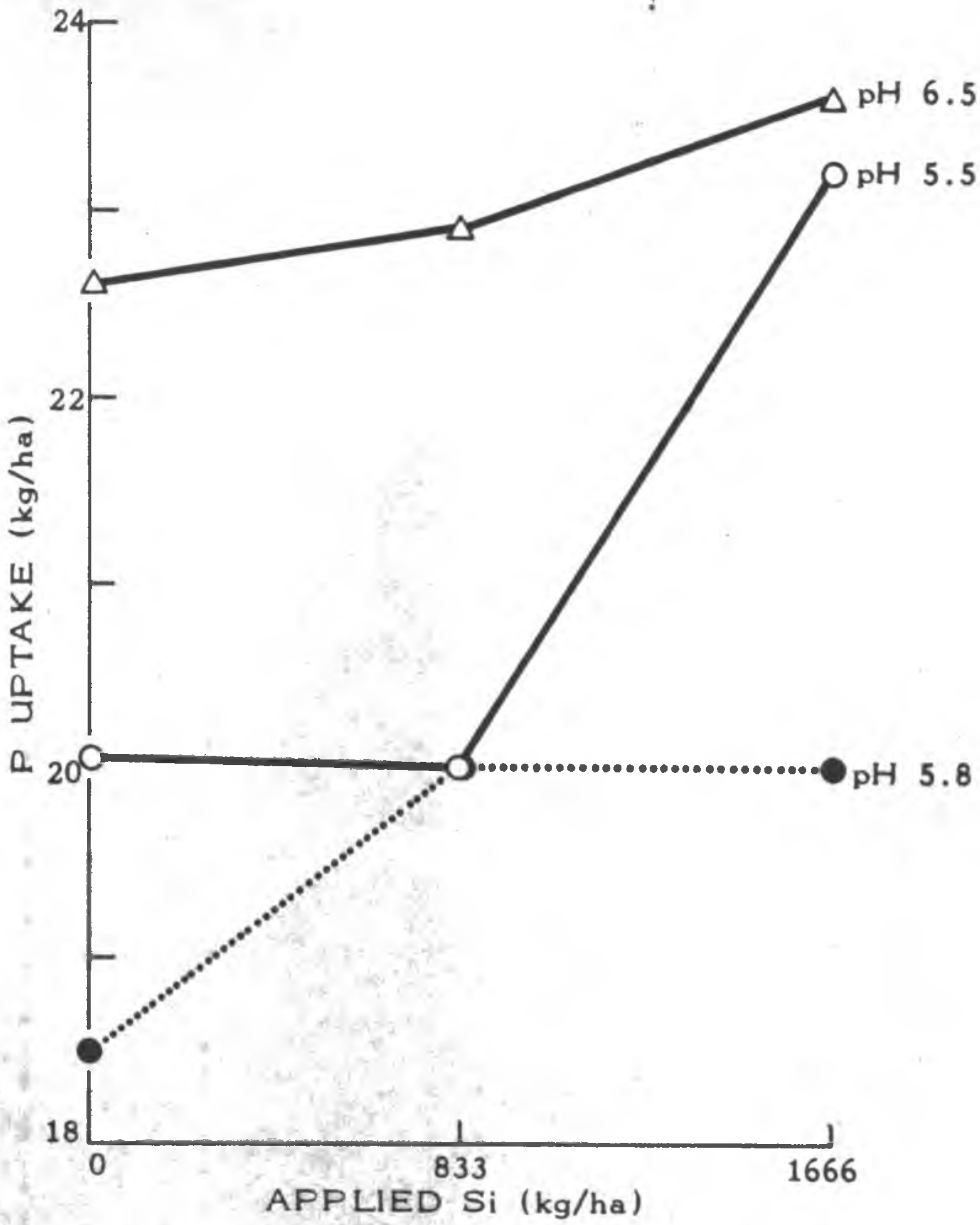

Figure 12. Influence of Residual Si and Soil pH on P Uptake.

when yield is plotted in the same manner as P uptake. When Figures 12 and 13 are compared it is obvious that P uptake is largely influenced by yield, however plant P concentrations caused additional modification of the trends. The curves in Figure 12 support the findings of Teranishi (1968) that Si application increased P uptake. The apparent irregularity of pH 5.8 is probably the result of deficiencies of other nutrients which limited yield.

The effect of residual Si on the internal P requirement of sugarcane is illustrated in Figure 14 which indicates that a particular concentration of sheath P is associated with higher yields with Si than without. When P uptake data by the plant and ratoon crops are combined to obtain total P uptake it was found that Si, P and pH treatments significantly affected P uptake.

Soil pH. The effects of Si and soil pH treatments on actual soil pH were found to be highly significant and positive, while increasing P also tended to increase soil pH. Observed soil pH values were generally lower than originally planned; however, they were approximately as expected in light of the data obtained from the plant crop. The average values for the three soil pH treatments were 5.5, 5.8 and 6.5. The variation in pH values observed may have been due to differences in mixing after application of soil amendments or to field variation which was not accounted for in the original lime applications which were based

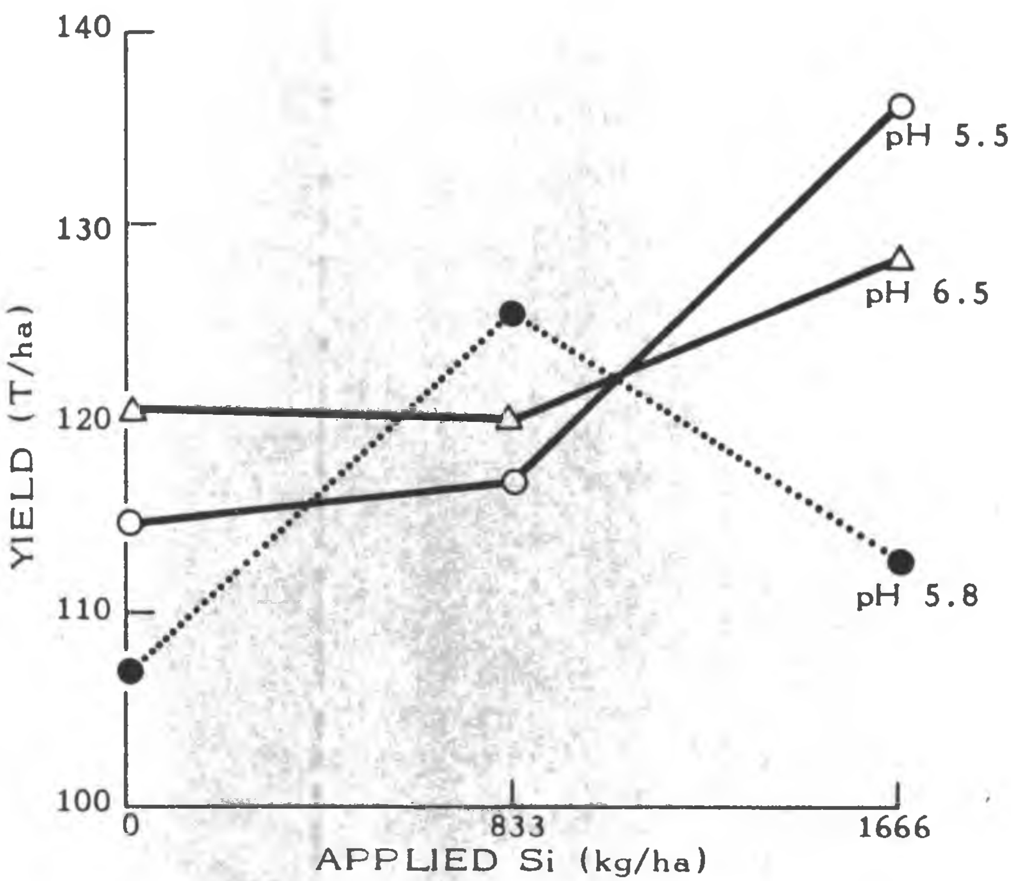

Figure 13. Influence of Residual Si and Soil pH on Yield of Sugarcane (Ratoon Crop) Harvested at Nine Months.

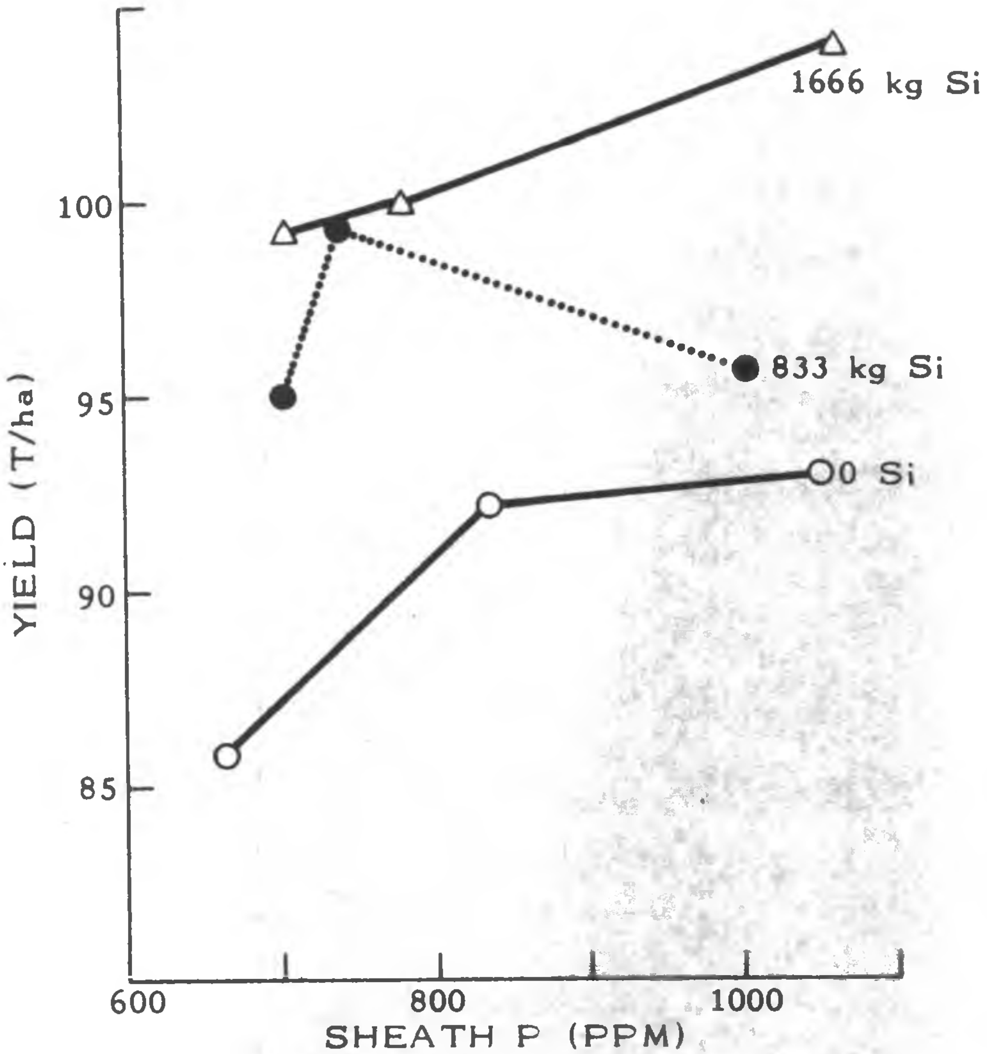

Figure 14. The Relationship Between Sheath P and Yield of Sugarcane Harvested at Nine Months as Influenced by Applied Si.

on the average pH of all plots in the field for simplicity.

Plant Nitrogen

There were no significant effects of Si, P or pH treatments on total plant N; however, there was a trend for whole plant N to decrease as Si increased and to increase as P increased. Also, there were no significant effects of treatments on N uptake. Nitrogen uptake tended to remain constant or increase slightly with Si and to increase slightly with P treatments. The average amount of N taken up was 5.4 kg N/ton (m) which is above the 4 kg per ton (m) (8 lbs per ton) level tentatively established for nine-month-old sugarcane by Stanford and Ayres (1964) as the internal N requirement for cane.

Potassium

Soil Potassium. The only significant factor affecting exchangeable soil K was the Si x P x pH interaction which was highly significant (Table 13). Some understanding of this interaction may be obtained by studying the various two factor interactions which are depicted in Figures 15 and 16. Figure 15 portrays the interaction of Si and P on soil K. Generally as Si and P increase, soil K at first increases and then decreases. The Si x pH interaction is shown in Figure 16, and it is apparent that soil K generally increases with increasing pH while it increases with increasing residual Si only at pH 6.5 and pH 5.5

Table 13. Analysis of Variance of Exchangeable Bases

Source of Variation	df	K	Ca	Mg
Whole Plots:				
Replications	2	1982.6	42022	4.83
pH	2	402.2	19150341**	1348.39*
Error (a)	4	345.5	515037	117.87
Subplots:				
Si	2	53.7	759500**	16.99
P	2	20.7	244296	11.06
Si x P	4	61.7	103216	54.16
Si x pH	4	58.4	36742	15.35
P x pH	4	71.7	27388	0.86
Si x P x pH	8	130.6**	85130	24.33
Error (b)	48	58.9	88915	42.03

*Significant at the 5% level.
**Significant at the 1% level.

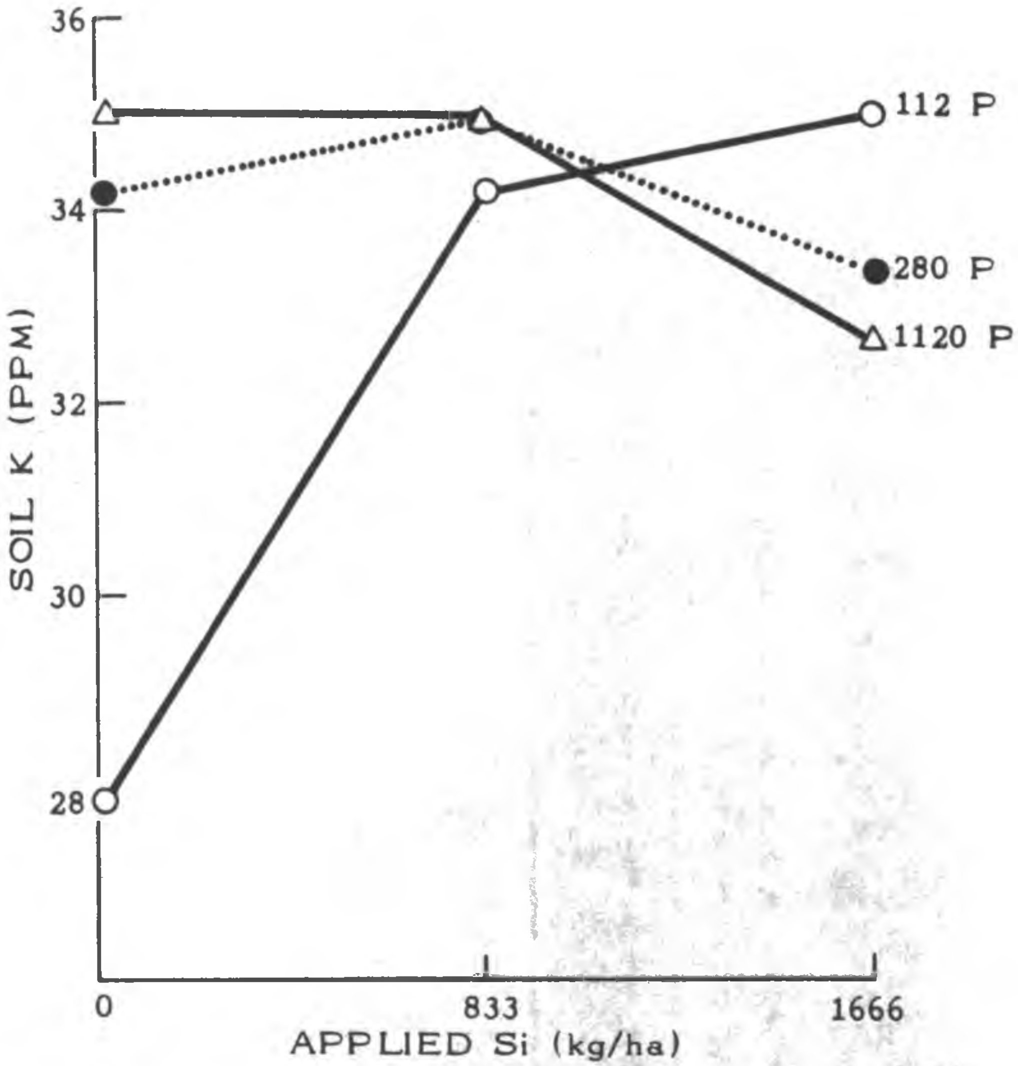

Figure 15. Influence of Residual Si and P on Exchangeable Soil K.

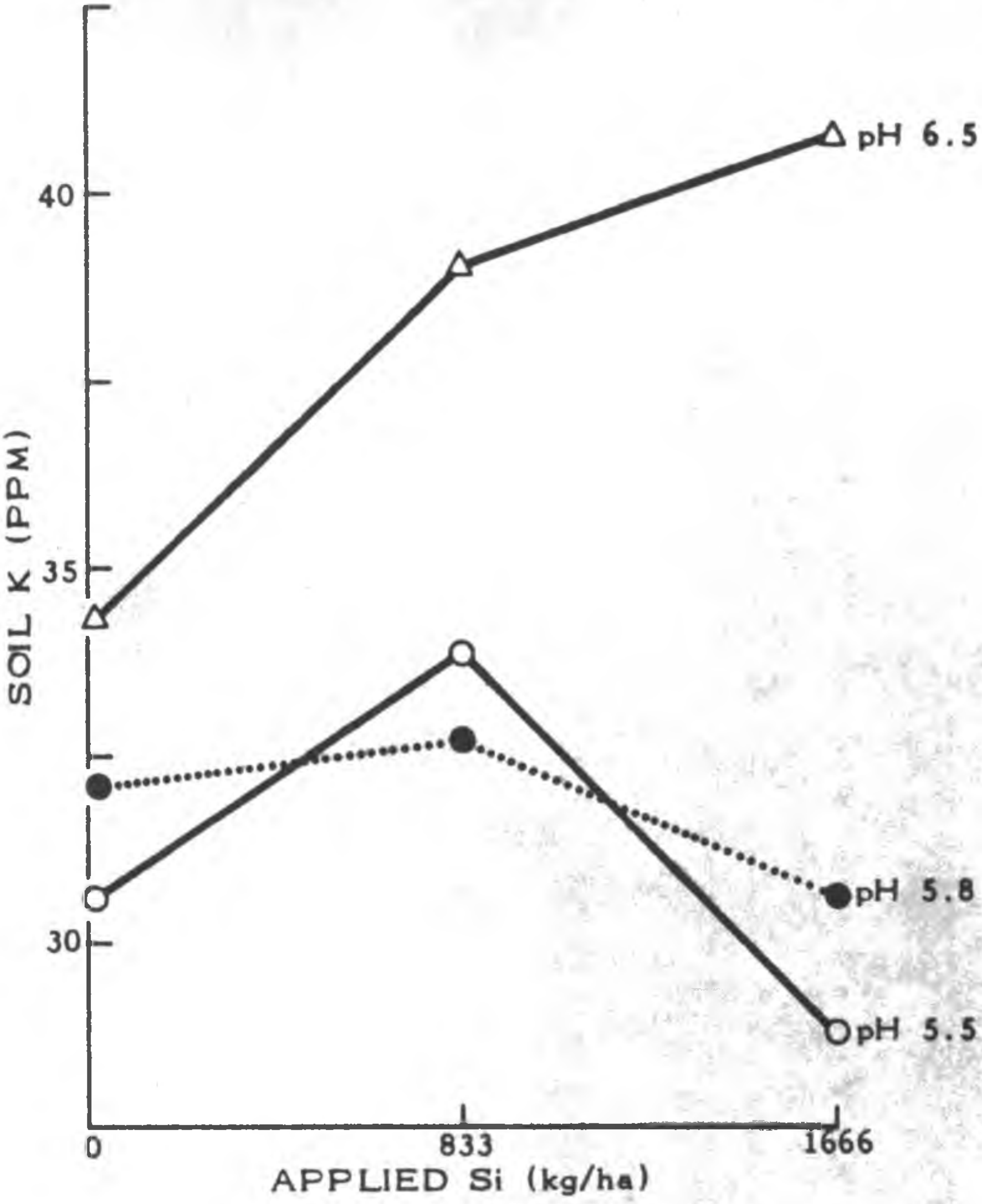

Figure 16. Influence of Residual Si and Soil pH on Exchangeable Soil K.

(833 kg Si only). The cause of this interaction is not completely clear; however, three important mechanisms appear possible: (1) K uptake by the previous crop as well as the present crop (assuming that highest K uptake occurred at the highest Si, P and pH levels), (2) the complimentary ion principle whereby Ca, which is supplied in the Si, P and pH treatments, is more easily displaced by K than is Al, and (3) an increase in net negative charge with increasing pH.

Plant Potassium. Sheath K at nine months was decreased significantly by increasing residual P levels (Table 14). A test of the means with Duncan's multiple range test showed that significantly lower sheath K values occurred in the high P treatment than in the low P treatment at all three sampling ages. In the nine-month samples significantly less sheath K was found in plots limed to pH 5.5 than in plots limed to pH 6.5. Similarly, K uptake was found to be significantly lower in the 1120 kg P level.

The sheath K data portrayed in Figure 17 offer strong evidence that a K differential was established by the plant crop. Those plots which received high Si and/or P applications in the plant crop must have removed more K from the soil so that less K was carried over for the ratoon crop. Since treatments did not have significant effects on yield of the ratoon crop, these differences may not be explained by a dilution effect.

Table 14. Analysis of Variance Summary for Plant Concentrations and Plant Uptake of K, Ca and Mg

Plant Concentration and Uptake of K, Ca and Mg	Source of Variation						
	Si	P	pH	Si x P	Si x pH	P x pH	Si x P x pH
K							
Sheath, 4 mo.		+			+		
Sheath, 8 mo.		+					
Sheath, 9 mo.		*	+		+		
Whole Plant		+			*		
Uptake of		+					+
Ca							
Sheath, 4 mo.		**	+				
Sheath, 8 mo.		*	+		*		
Sheath, 9 mo.			*				
Whole Plant							
Uptake of	**	*		*			+
Mg							
Sheath, 4 mo.							
Sheath, 8 mo.							
Sheath, 9 mo.							
Whole Plant							
Uptake of					+		

+ = Significant at the 10% level.
* = Significant at the 5% level.
** = Significant at the 1% level.

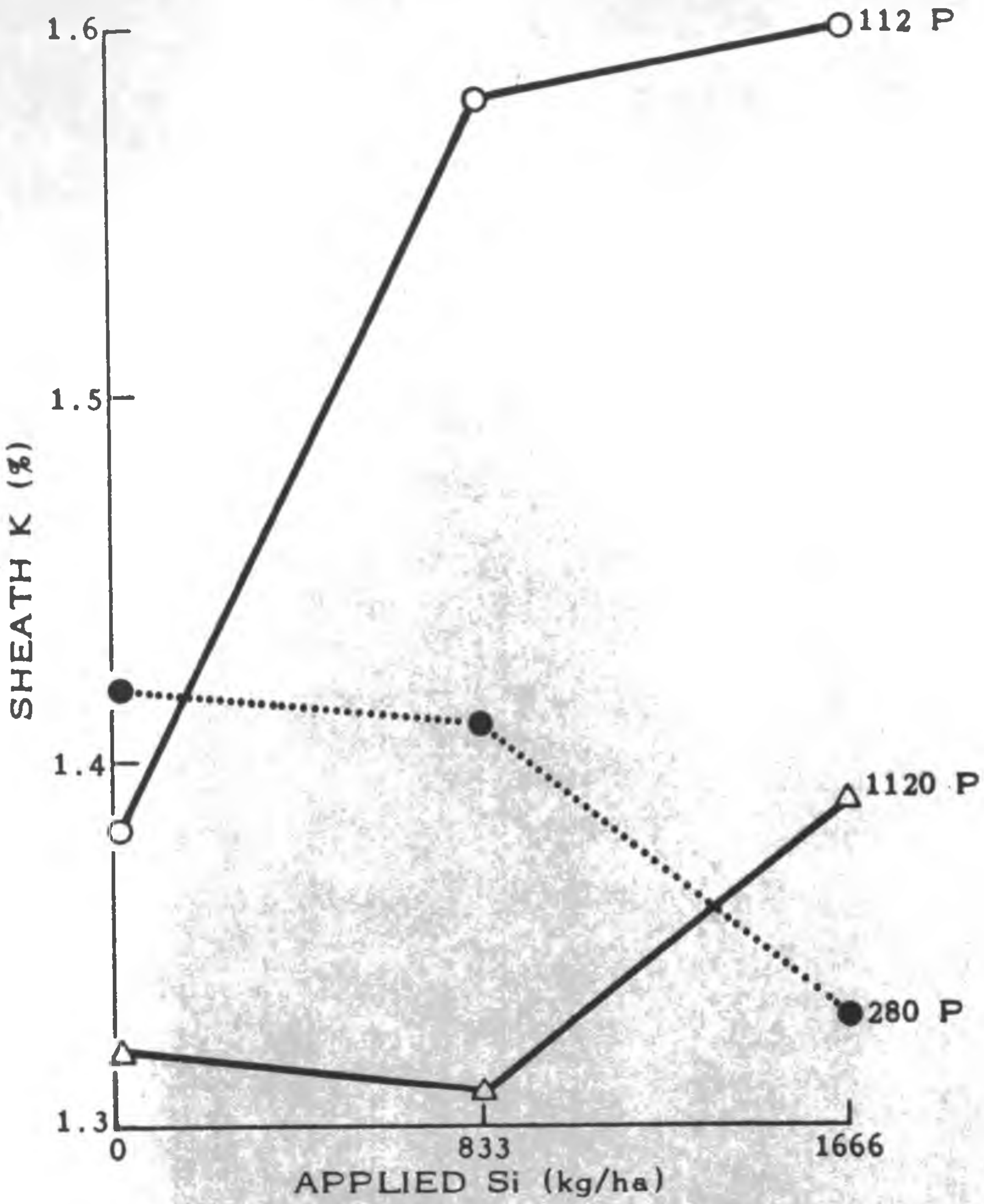

Figure 17. Influence of Residual Si and P on Sheath K (Nine-Month Sample).

The sheath K levels in Figure 17 are generally low and are below the 2.25 percent K level, oven dry basis, which Humbert (1964) reported to be critical for sugarcane. The average sheath K values for four, eight and nine months were 2.26, 1.82 and 1.41 percent K, respectively, which indicate that the experiment suffered from K deficiency in the eight- and nine-month period and possibly earlier. The application of K (224 kg/hectare) which was made before the plant crop gave high sheath K values in the four months samples of the plant crop. Since this application is adequate for a two-year sugarcane crop in some areas, it was assumed to be adequate for two nine-month sugarcane crops. However, high rainfall at the test site as well as high K uptake of the plant crop apparently depleted the supply of soil K to critical levels in the ratoon crop. Also, in a two-year crop K would have been recycled but in this cropping system it was removed.

Figure 18 depicts the Si x pH interaction which had a significant effect on whole plant K. This interaction may be explained by the fact that K was retained by the soil against leaching in treatments having higher soil Ca levels, i.e., high pH and Si treatments, since Ca rather than Al was the complimentary ion, and also in treatments with higher pH which produced a net increase in the negative charge. Simultaneously, K was being removed differentially by high and low yielding treatments in the plant crop, such as: high pH, Si and P treatments; and

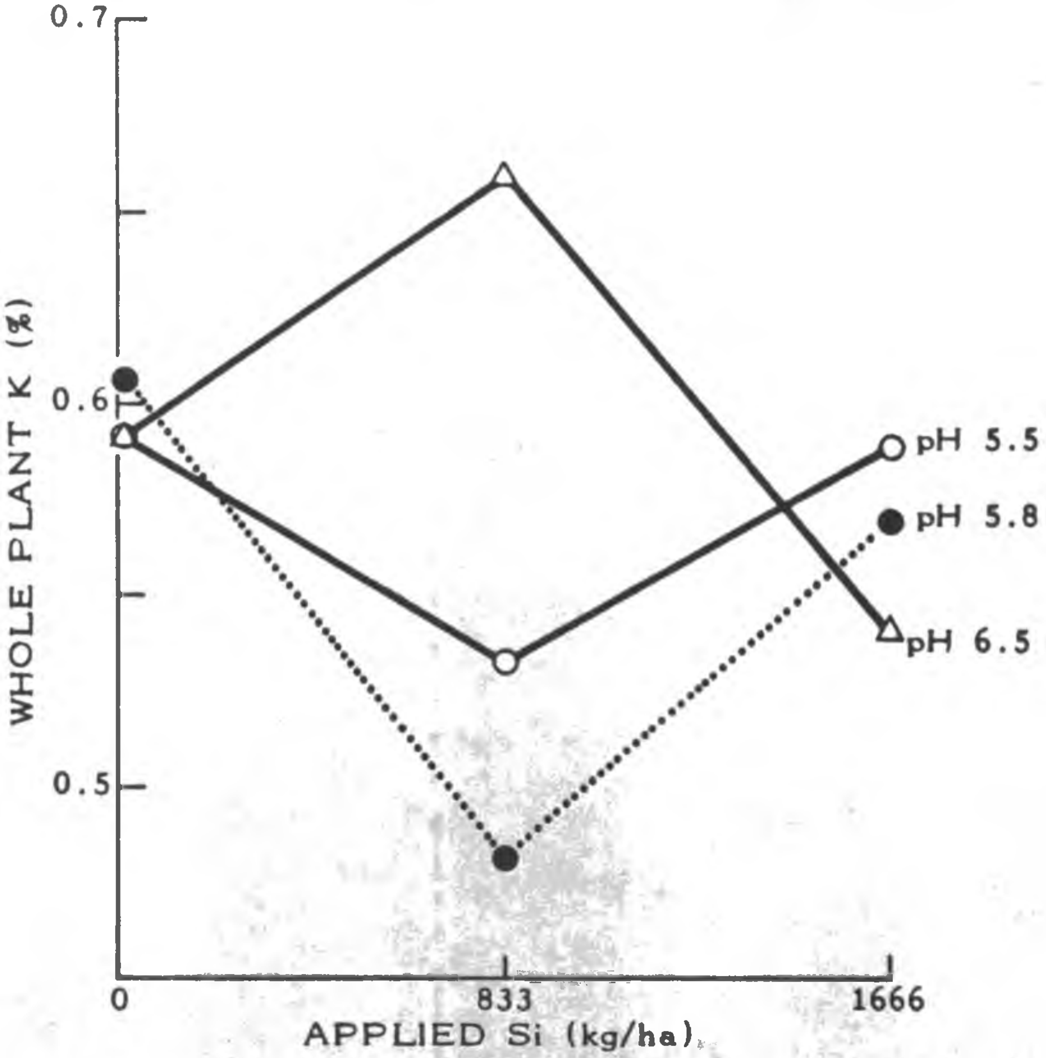

Figure 18. Influence of Residual Si and Soil pH on Whole Plant K.

low pH, Si and P treatments, respectively (Figure 19). Varying intensities of these three forces may be used to explain the general trends shown in Figure 18. At pH 5.8, K retention was relatively low because of lower soil Ca while K uptake was relatively high because of higher yields in the plant crop; therefore, total K available to the ratoon crop was relatively low. At pH 5.5, however, K retention was low, but K uptake by the plant crop was lower than that at pH 5.8 due to low plant crop yields; therefore, K available to the ratoon crop would be higher than at pH 5.8. At pH 6.5 K retention and K uptake were higher than at pH 5.8 due to the high levels of Ca and to the high plant crop yields in this treatment, respectively. Since whole plant K in the ratoon crop (Figure 18) is much higher at pH 6.5 than at pH 5.8 or 5.5, the logical conclusion is that the effect of soil K retention was greater than the effect of depletion by the previous crop. The total K uptake curves in Figure 20 show the effects of these two opposing forces quite clearly and confirm the explanation offered above.

Calcium

Soil Calcium. Silicon and soil pH treatments resulted in significant increases in soil Ca (Table 13, Figure 21). Analysis of the soil Ca data by Duncan's multiple range test indicated that exchangeable Ca increased significantly as residual Si, P and

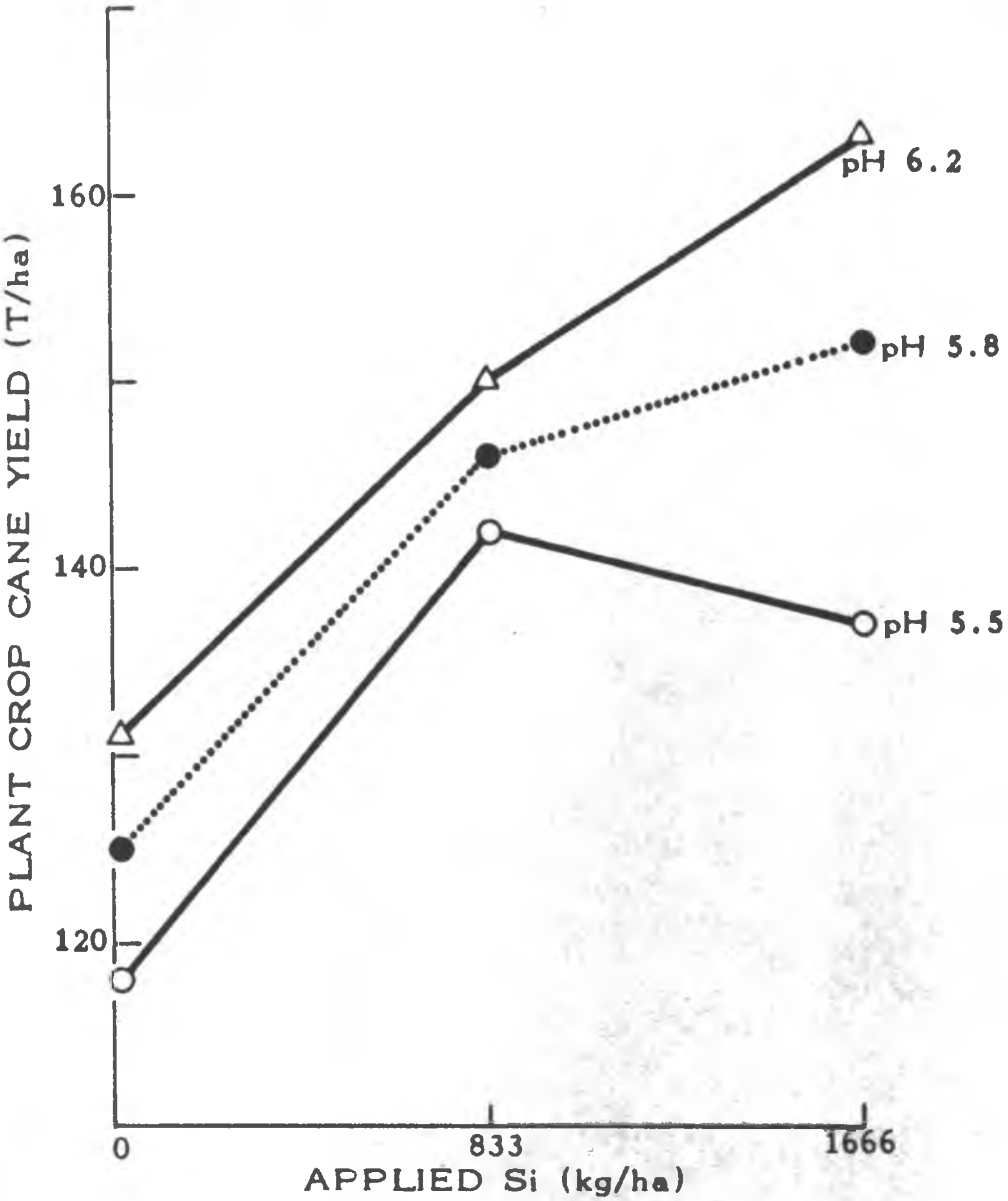

Figure 19. Influence of Applied Si and Soil pH on Yield of Sugarcane (Plant Crop) Harvested at Nine Months.

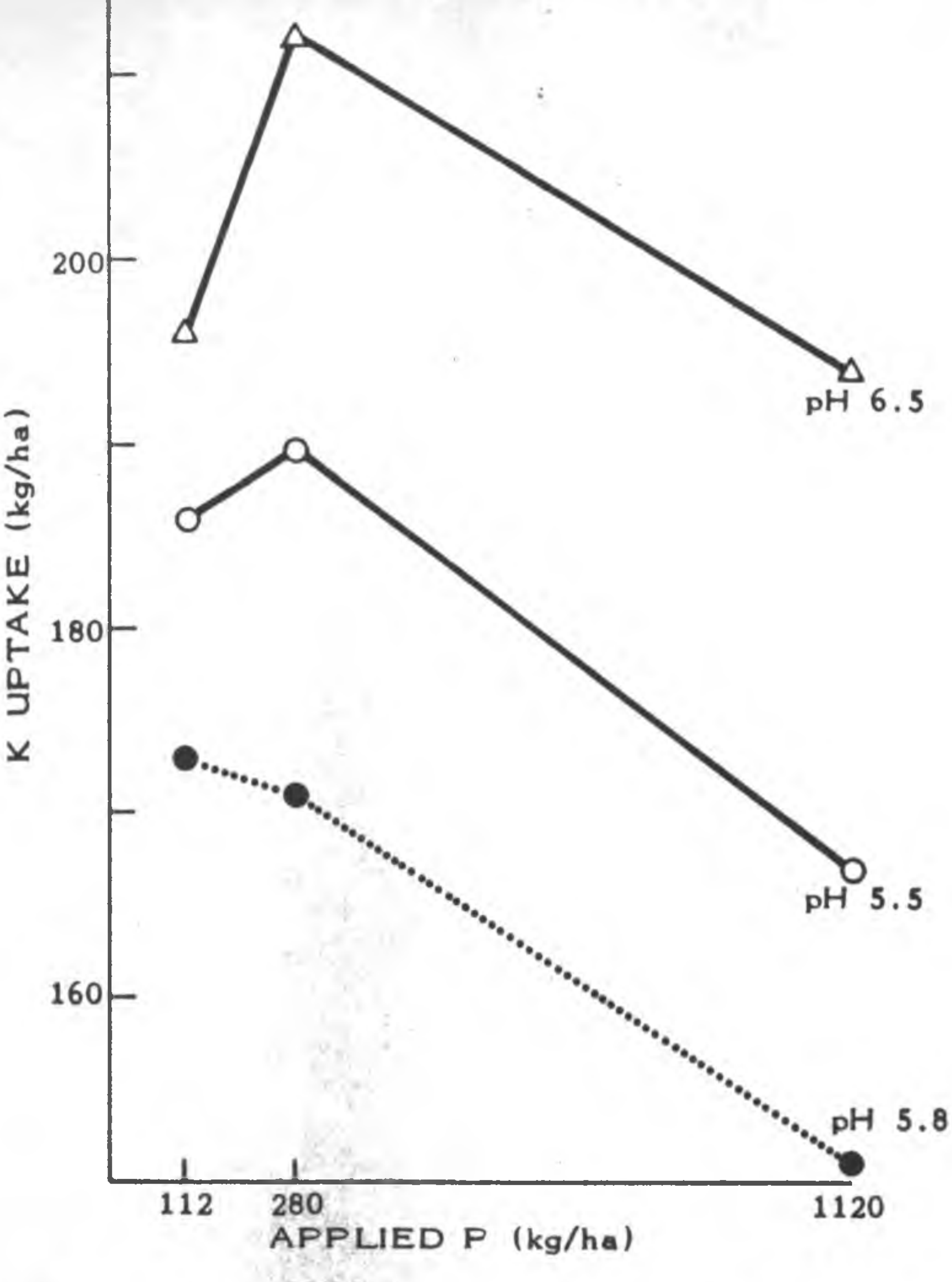

Figure 20. Influence of Residual P and Soil pH on K Uptake.

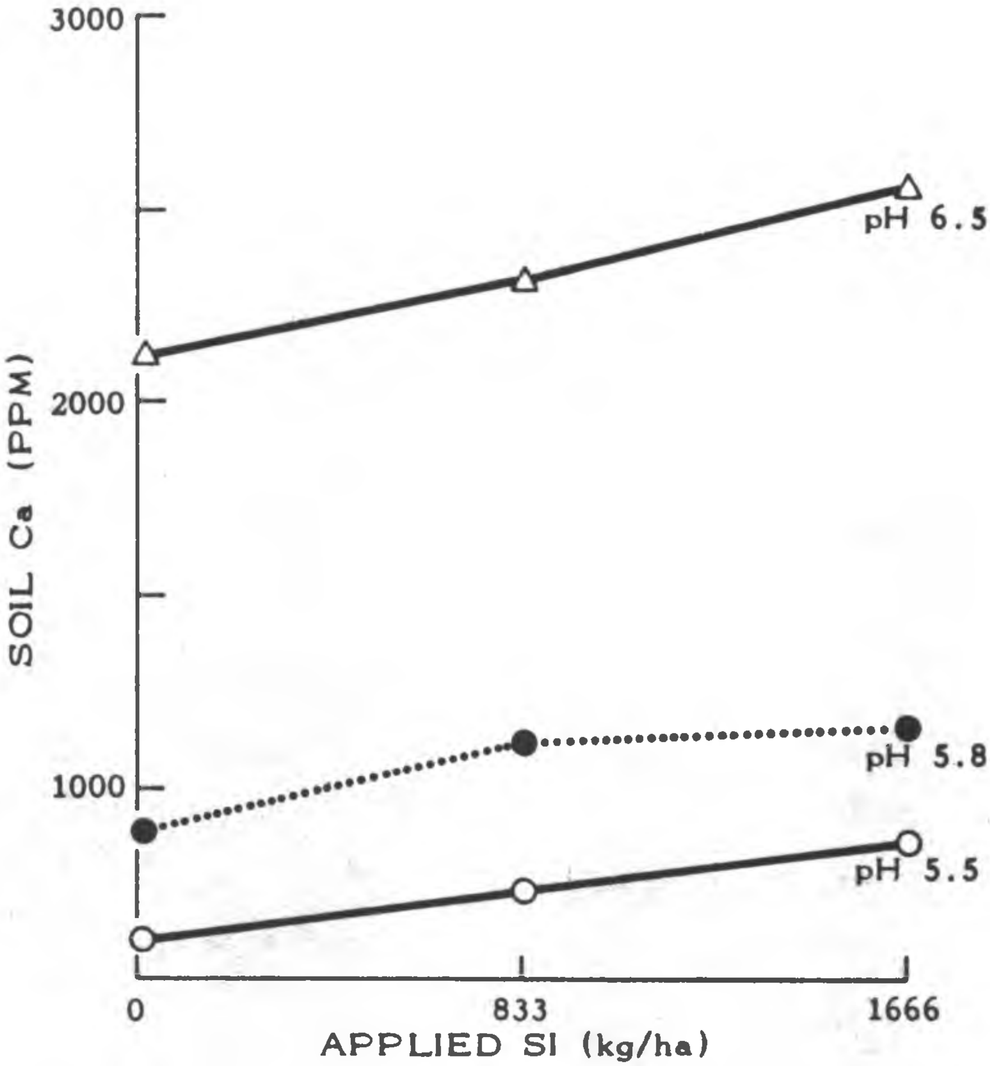

Figure 21. Influence of Residual Si and Soil pH on Exchangeable Soil Ca.

soil pH increased to the highest levels.

It is interesting to note that the differences in soil Ca due to P application were still discernible after 18 months of intensive cropping and moderately heavy rainfall (data not shown). (See Appendix B, Table 36.)

Plant Calcium. Sheath Ca, at four and eight months, was significantly affected by residual P application; at eight and nine months sheath Ca was significantly affected by the Si x P interaction and soil pH treatment, respectively (Table 14). Sheath Ca, which is represented by the four-month samples in Figure 22, was in every case higher than the critical levels described in the literature and often two- to four-fold higher. Thus Ca should not have limited growth in any way. Whole plant Ca was not affected by any treatments, but Ca uptake was significantly increased by residual Si and by residual P. The Si x P interaction was also significant. Calcium uptake increased with residual Si and P and was apparently a direct function of yield.

Magnesium

Soil Mg was significantly increased by pH treatments (Table 13, Figure 23) and analysis by Duncan's multiple range test indicated that soil Mg at pH 6.5 was significantly higher than soil Mg at pH 5.5 or 5.8. This increase with increasing pH was expected since soil Mg availability increases with pH (Buckman

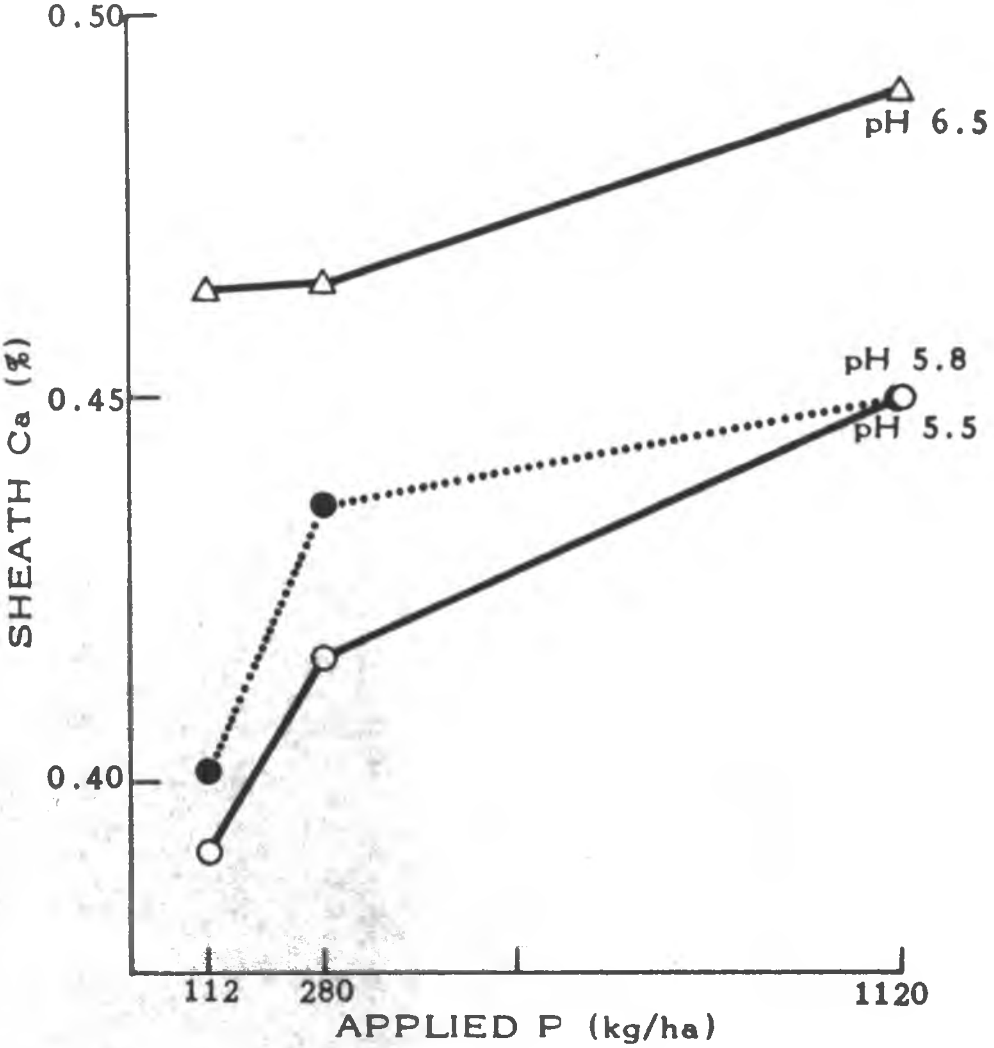

Figure 22. Influence of Residual P and Soil pH on Sheath Ca (Nine-Month Sample).

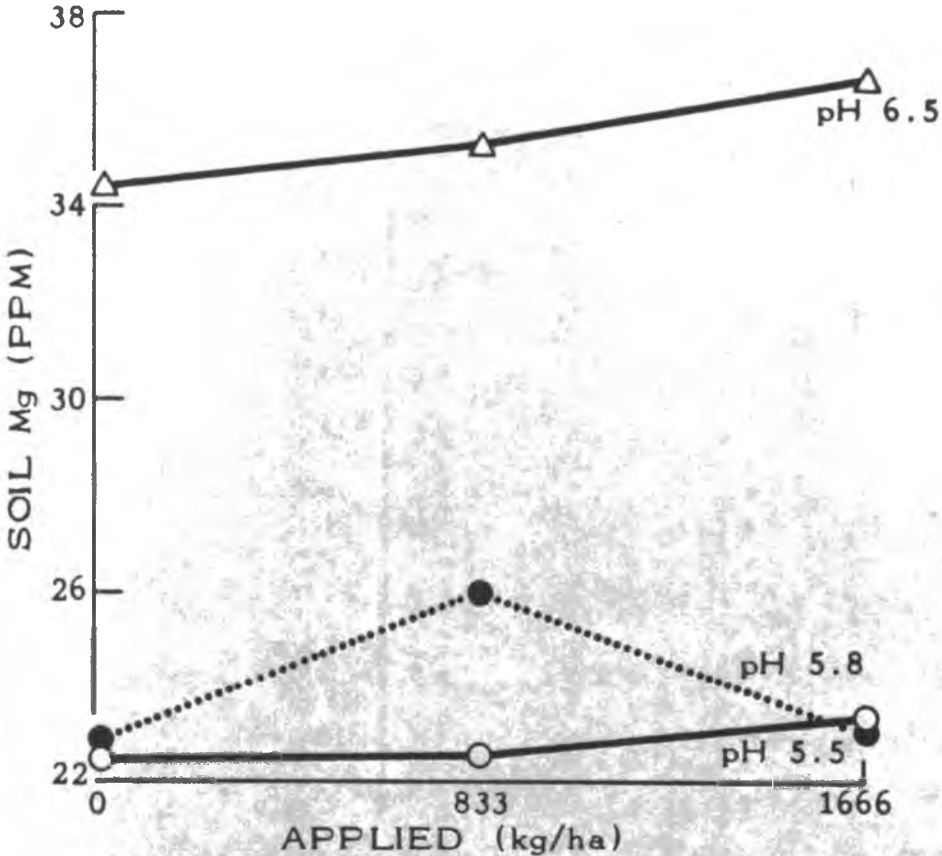

Figure 23. Influence of Residual Si and Soil pH on Exchangeable Soil Mg.

and Brady, 1965. Also, Mg was added in the Si applications and the pH treatments. The average exchangeable Mg value was 27 ppm, and since sugarcane usually responds to Mg application when exchangeable Mg falls below 30 ppm (Humbert, 1964), Mg may have limited growth in some plots. Sheath Mg was not significantly affected by treatment (Table 14); however, sheath Mg of the nine-month sample (Figure 24) tended to decrease strongly with increasing Si. Apparently Mg was generally affected by complimentary ion, pH dependent charge, and uptake effects as was K, but, in the case of Mg, the effect of uptake by the previous crop was greater than that of the complimentary ion.

Plant Manganese

Sheath Mn was affected by residual Si treatment at the 1 percent level in all three sampling ages (Table 15). At the four and eight months samples the Si x pH interaction was also significant. The only significant factor in the analysis of variance of whole plant Mn was the Si x pH interaction. Applied Si had no effect on sheath Mn in the plant crop and no explanation for this is apparent. The Si x pH interaction of the nine-month sample in Figure 25 represents the general patterns followed at all three sampling ages. Sheath Mn levels at pH 6.5 are lower than at either pH 5.8 or 5.5 and they are also lowest at the high Si level. At each sampling age, the highest sheath level is at pH

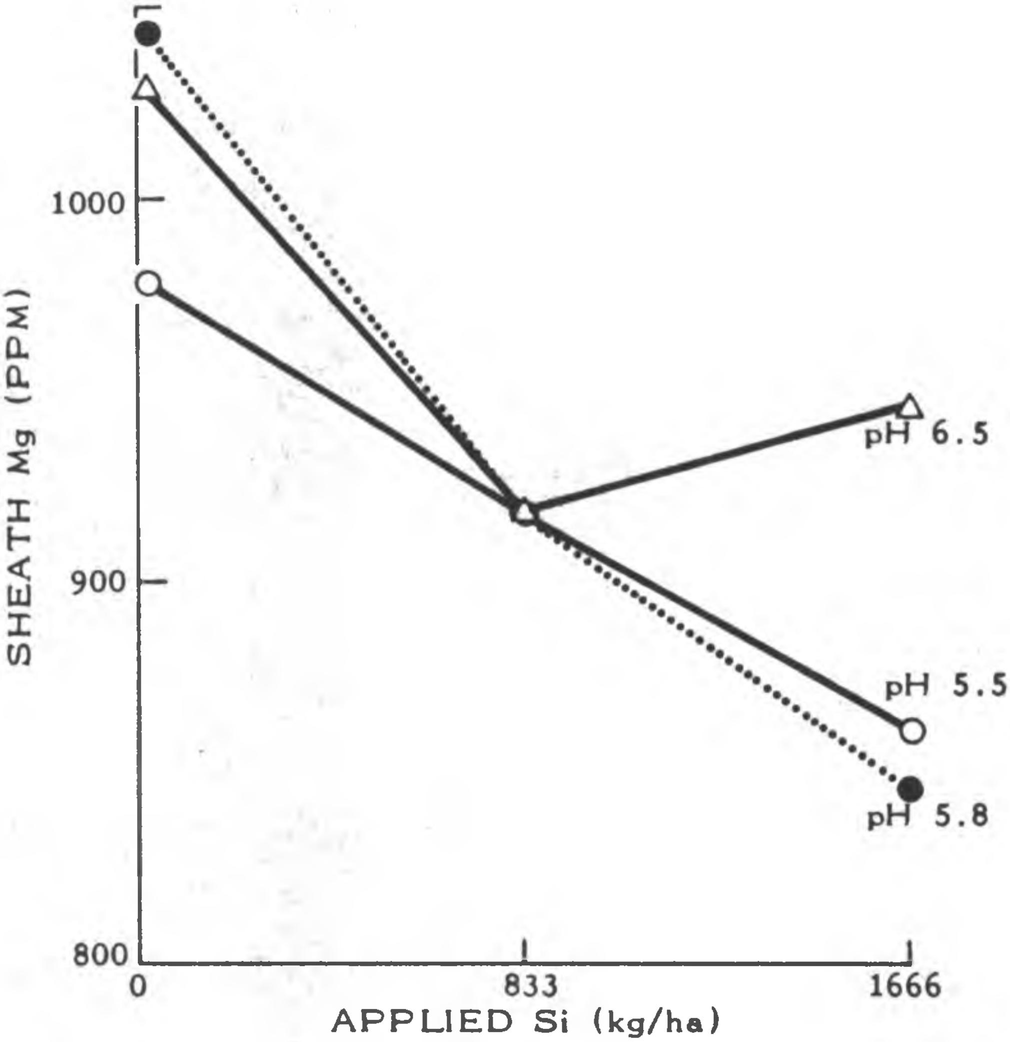

Figure 24. Influence of Residual Si and Soil pH on Sheath Mg (Nine-Month Sample).

Table 15. Analysis of Variance of Plant Mn

Source of Variation	df	Sheath (mo.)			Whole Plant	Uptake
		4	8	9		
		mean squares				
Whole Plots:						
Replications	2	22550	12538	3090	1654	1.340
pH	2	17700	9041	3157	1100	0.762
Error (a)	4	6455	2975	1634	499	0.463
Subplots:						
Si	2	9218**	3456**	1422**	100	0.092
P	2	171	195	37	58	0.020
Si x P	4	250	261	63	57	0.058
Si x pH	4	3341*	1809**	427	214*	0.451
P x pH	4	429	72	110	59	0.139
Si x P x pH	8	565	644	41	57	0.096
Error (b)	48	1031	306	190	70	0.072

*Significant at the 5% level.
**Significant at the 1% level.

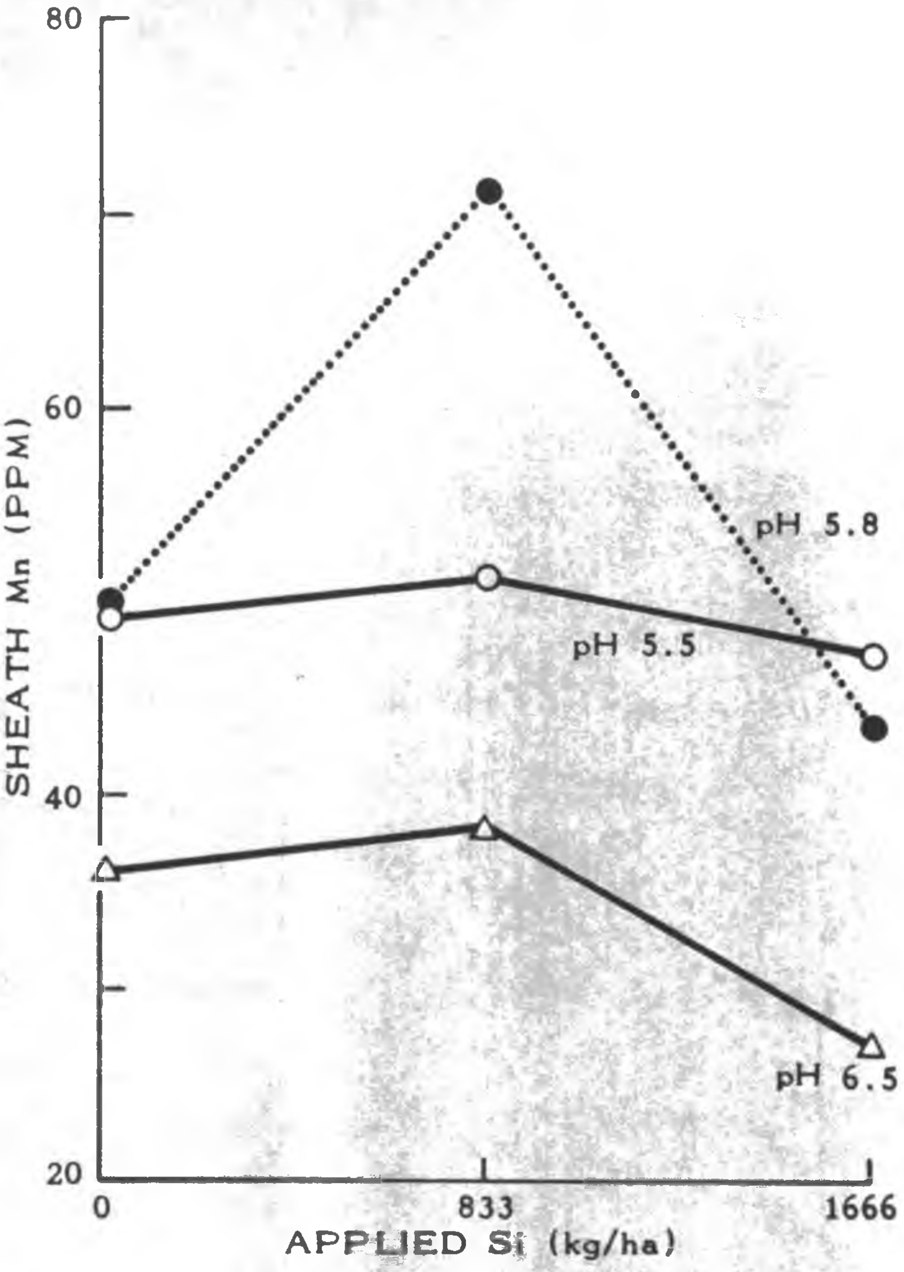

Figure 25. Influence of Residual Si and Soil pH on Sheath Mn (Nine-Month Sample).

5.8 with 833 kg Si; the reason for this is not apparent. Analysis by Duncan's multiple range test indicates that while the differences due to residual Si are highly significant, the differences due to pH are non-significant.

Aluminum

Highly significant decreases in KCl extractable soil Al were found with increasing residual Si and soil pH. Also, significant Si x pH and Si x P x pH interactions were found (Table 16). Analysis by Duncan's multiple range test indicated that the no Si treatment was significantly different from the medium and high Si treatments (Figure 26). Teranishi (1968) found these same trends but they were not significant for the plant crop. It is well known that extractable Al decreases with increasing pH (Magistad, 1925). The trend of decreasing Al with increasing residual Si must be a function of the amounts of Al precipitated from soil solution as aluminum silicate and aluminum hydroxide with the resulting decrease in activity of the Al ion. This in turn readily explains the Si x pH interaction observed, i.e., when there is no soluble Al, Si has no effect.

Sheath Al at four months was significantly affected (1% level) by residual Si treatments, and a significant (5% level) Si x P interaction was also observed. Residual P had a significant effect at the nine-month sampling (Table 17). Analysis by Duncan's

Table 16. Analysis of Variance of Soil Al

Source of Variation	df	Mean Squares
Whole Plots:		
Replications	2	1.494
pH	2	1417.881**
Error (a)	4	16.462
Subplots:		
Si	2	152.727**
P	2	19.130
Si x P	4	35.873
Si x pH	4	56.027*
P x pH	4	22.414
Si x P x pH	8	37.404*
Error (b)	48	16.819

*Significant at the 5% level.
**Significant at the 1% level.

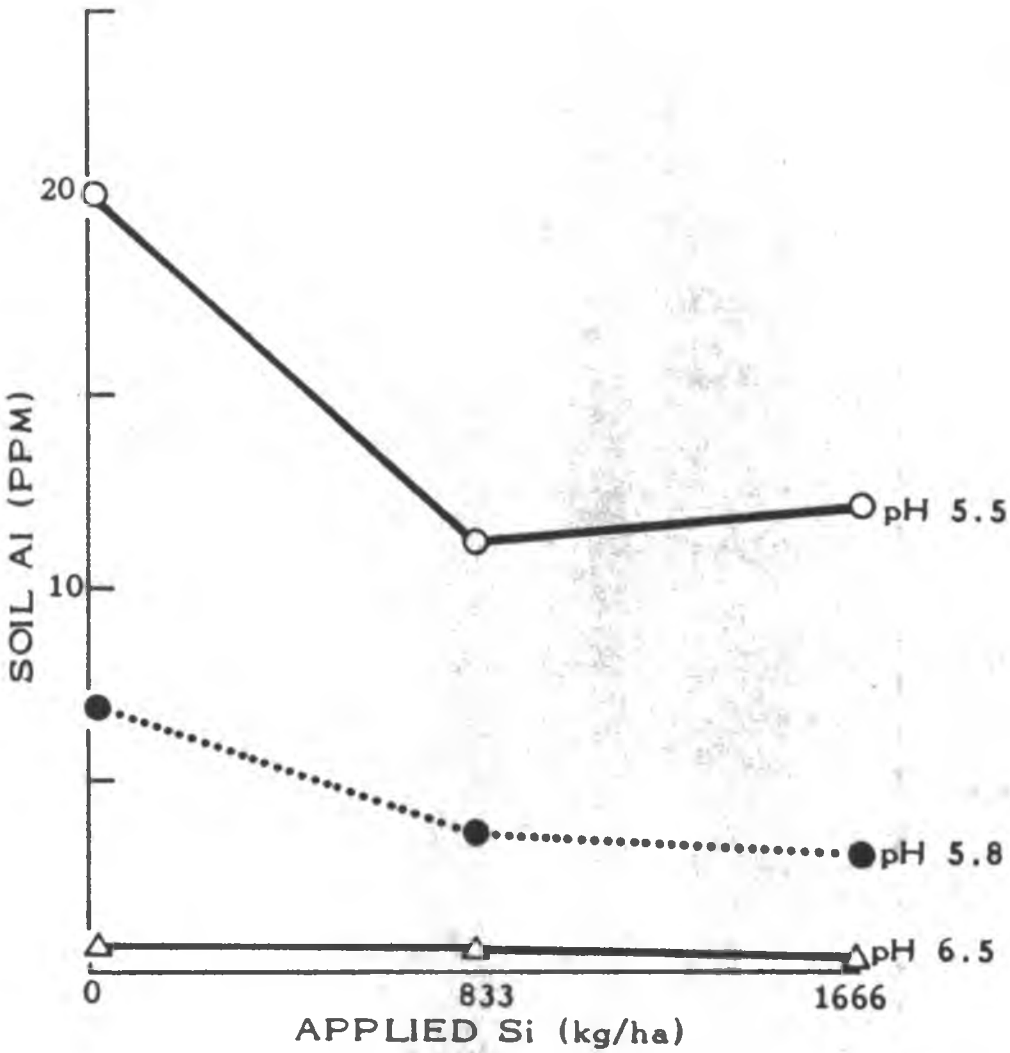

Figure 26. Influence of Residual Si and Soil pH on KCl-Exchangeable Soil Al.

Table 17. Analysis of Variance of Plant Al

Source of Variation	df	Sheath (mo.) 4	8	9	Whole Plant	Uptake
		mean squares				
Whole Plots:						
Replications	2	372	1938	330	990	0.763
pH	2	8	72	1	512	1.159
Error (a)	4	327	1007	66	1229	1.098
Subplots:						
Si	2	667**	1234	1	1001	1.994
P	2	96	638	72*	1667	0.658
Si x P	4	354*	723	16	1824	1.656
Si x pH	4	35	869	33	869	0.568
P x pH	4	221	671	18	372	0.768
Si x P x pH	8	112	837	15	1274	0.913
Error (b)	48	114	673	19	1284	1.008

*Significant at the 5% level.
**Significant at the 1% level.

multiple range test indicated that sheath Al was significantly higher in the high Si treatment than in the low or medium Si treatments at the four-month sampling (Figure 27). This effect could conceivably be caused by the precipitation of most of the soluble Al by Si, thus preventing deposition of Al on roots and allowing greater absorption of the small amounts of Al still present in solution at high Si levels. Applied P may also have the same effect on Al solubility.

Multiple Regression Analysis

Multiple regression analyses were run to help interpret interrelationships between yield, soil factors and plant factors. The relationships for yield and each of the major elements will be discussed in this section.

Yield. Teranishi (1968) found that an equation with Si, P and pH treatments, their interactions and squares, and 19 soil and plant analyses accounted for only 59 percent of the yield variation. These parameters included soil and sheath Si, P and Al as well as TCA extractable sheath Si and sheath Ca and Mn. He suggested that other nutrients may be responsible for the unexplained yield variation. In the present study an attempt was made to measure these other sources of variation in the ratoon crop to determine if more yield variation could be explained. A table of the parameters measured and the associated coefficients

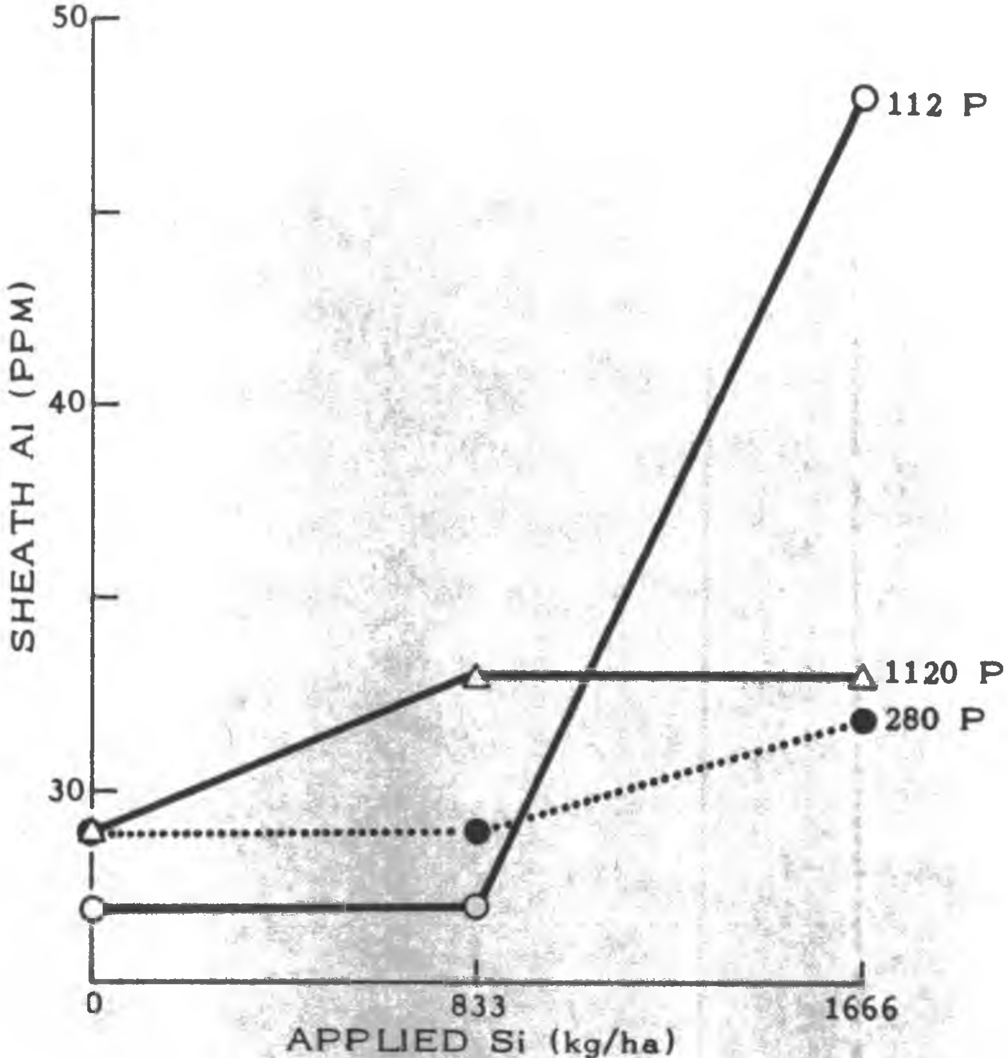

Figure 27. Influence of Residual Si and P on Sheath Al (Four-Month Sample).

of determination (R^2 x 100) for the yield equation calculated by a step-wise regression analysis is presented in Appendix B, Table 43. The 48 variables accounted for 73 percent of the yield variation. When all 55 variables were included 77 percent of the variation was explained. Other sources of variation which were not measured are field variation, differential ratooning, rat damage, soil and plant nutrients not measured, and measurement of yield. The coefficients of variation for soil and plant analyses presented in Appendix B, Table 45 indicate the relative amounts of variation in these measurements. The highest values were found for plant and soil Al (47% and 64%, respectively) and the lowest values were found for sheath moisture (1%).

The large number of variables required to explain the variation in yield for the ratoon crop is reflected in the fact that no single parameter accounted for more than seven percent of the total variation. Most of the variation in the plant crop was accounted for by the treatments while in the ratoon crop, treatments accounted for a relatively small part of the variation. This difference may be due to removal of applied nutrients by leaching, uptake by the plant crop or by fixation. Whole plant Si, Ca, Mg and Al and TCA Si were the most important plant variables affecting yield in the ratoon crop and were second only to the effect of applied Si. Of the soil factors, soil Ca and soil Si were the only variables that explained more than one percent of the yield variation. This is further illustrated by the data in Table 18 which shows the effect on ratoon crop yield of soil and applied factors and plant crop yield. These parameters account for only 13 percent of the total variation in yield which indicates the relatively small influence of soil and applied factors on yield of the ratoon crop.

A prediction equation which included all variables explaining one percent or more of the yield variation was derived. The twenty variables, listed in Table 19, explained 63 percent of the yield variation in the ratoon crop as compared to eleven variables which explained 44 percent of the yield variation in the plant crop. Factors included in the equation for the ratoon crop, but not for the plant crop, are green sheath weight, sheath moisture, plant N and Mg, and plant and soil K.

A yield prediction equation based on sheath values of the four-month samples indicated that Mg, Mn and Si concentrations were important. A similar equation based on sheath values for the eight-month samples indicated that green sheath weight, Si, Mg, K and sheath moisture were important. These equations, however, accounted for only 18 and 12 percent of the yield variation, respectively. Sheath Si and Mg were apparently the most important parameters as they were included in both equations.

Silicon. Variables which affected water-extractable soil Si levels were identified by use of regression analysis (Equation 1).

Table 18. Correlation Coefficients Obtained from a Step-Wise Regression Analysis of Applied Si, P and pH, Their Squares and Interactions, Soil Factors and Previous Yield on Cane Yield at Nine Months as Indicated by R and R^2 Values and Simple Correlation Coefficients Between These Factors and Yield

Variable	R[1/]	R^2	Simple Correlation Coefficients (r)
Applied Si	0.246	0.061	.246*
Previous Yield	0.264	0.070	.156
Soil P	0.289	0.084	.100
Soil Si (modified Truog)	0.300	0.090	.241*
Soil Si (water extractable)	0.307	0.094	.171
pH^2	0.316	0.100	.067
Soil Ca	0.345	0.119	.116
Si^2	0.359	0.129	-.106

[1/] The R value applies to the relationship between the variable opposite it as well as all those above it and yield in a multiple regression analysis.

*Significant at the 5% level.

Table 19. Correlation Coefficients Obtained from a Step-Wise Regression Analysis of Soil and Plant Variables on Cane Yield as Indicated by R and R^2 Values and the Simple Correlation Coefficients Between These Factors and Yield

Variable	Age (mo.)	R[1/]	R^2	Simple Correlation Coefficients (r)
Green sheath weight	9	0.28	0.08	.285
Whole plant Mg	9	0.39	0.16	-.241*
Soil Si (modified Truog)	9	0.46	0.21	.171
Whole plant Al	9	0.50	0.25	-.188
Soil K	9	0.53	0.28	-.011
Green sheath weight	8	0.55	0.31	.182
Residual applied P		0.58	0.33	.060
Whole plant P	9	0.64	0.41	-.189
Sheath Al	8	0.65	0.43	.057
Whole plant Si	9	0.67	0.45	.197
TCA sheath Si	4	0.70	0.50	.031
Soil pH	9	0.72	0.52	.059
Sheath moisture	9	0.74	0.54	-.009
Sheath Mg	9	0.75	0.56	-.240*
Sheath Al	9	0.76	0.57	-.162*
Sheath Al	4	0.77	0.59	.023
Whole plant N	9	0.77	0.60	-.131
TCA sheath Si	9	0.78	0.60	.164
Sheath K	8	0.78	0.61	.134
Whole plant K	9	0.79	0.63	.018

[1/] The R value applies to the relationship between the variable opposite it as well as all those above it and yield in a multiple regression analysis.

*Significant at the 5% level.

Water extractable soil Si was found to increase with applied Si, soil Si (modified Truog), and soil P and decrease with soil pH and soil Al.

$$\text{Soil Si } (H_2O) = 4.36 + 0.22 \text{ (Applied Si)} - 0.68 \text{ (pH)} + 0.0034 \text{ (Soil Si, Modified Truog)} + 0.0007 \text{ (Soil P)} - 0.012 \text{ (Soil Al)} \quad (1)$$

These five variables accounted for some 80 percent of the soil variation and followed expected trends. When whole plant Si was related to all preharvest factors it was found that soil Si (water extractable), whole plant Ca, sheath Al (four month), yield, and sheath moisture were positively related to total plant Si while sheath Ca (nine months), and soil Si (modified Truog) were negatively associated with whole plant Si.

$$\text{Whole Plant Si} = -8494 + \text{SiO}_8 \text{ (Soil Si, } H_2O) + 0.68 \text{ (Whole Plant Ca)} + 10.1 \text{ (Sheath Al, 4 Months)} - 0.25 \text{ (Sheath Ca, 9 Months)} + 375 \text{ (Applied Si)} - 6.54 \text{ (Soil Si, Modified Truog)} + 6.00 \text{ (Yield)} + 90.6 \text{ (Sheath Moisture, 9 Months)} \quad (2)$$

This equation accounted for 86 percent of the variation in total plant Si. Thus a large percentage of the variation in both soil and plant Si was explained by the variables measured in this study.

<u>Phosphorus</u>. An equation (3) for soil P which included both applied and soil factors indicated that only applied P and

modified Truog extractable soil Si explained more than one percent of the variation in soil P.

$$\text{Soil P} = -8.22 + 0.20\ (\text{Applied P}) + 0.21\ (\text{Soil Si, Modified Truog}) \quad (3)$$

These two factors accounted for 85 percent of the variation in soil P and most of this variation (82%) was accounted for by applied P alone. The modified Truog extractable Si may be more closely related to extractable P than to water extractable Si because the former is a capacity factor while the latter is an intensity factor. Thus the amount of extractable P was a function of the amount of fixed Si rather than the amount of soluble Si. When applied factors were eliminated from equation (3) a new equation (4)

$$\text{Soil P} = 543 + 0.08\ (\text{Soil Ca}) - 93.1\ (\text{Soil pH}) \quad (4)$$

explained only ten percent of the variation in soil P. The negative effect of soil pH was not expected and is probably due to the high correlation between soil Ca and pH ($r = 0.92$). This would result in a reduction in the contribution of soil pH to variation in soil P once soil Ca had been included in equation (2) and vice versa. Therefore other factors varying with pH may be responsible for the apparent negative effect of pH.

Whole plant P decreased with yield but increased with the other factors in equation (3) which explained 87 percent of the whole plant P variation.

$$\begin{aligned}\text{Whole Plant P} = 54.4 &+ 0.208\ (\text{Applied P}) \\ &+ 0.108\ (\text{Whole Plant Ca}) \\ &+ 0.216\ (\text{Sheath P, 8 Months}) \\ &+ 0.324\ (\text{Whole Plant K}) \\ &- 0.887\ (\text{Yield}) \qquad (3)\end{aligned}$$

This decrease with yield and increase with applied P are expected due to the effects of dilution and P addition, respectively. The other three variables are probably associated with whole plant P rather than being causal factors.

Bases. Soil K was found to increase with soil Ca, Mg, and water extractable Si and decrease with soil pH, P and modified Truog extractable Si. Equation (4), which included all soil factors accounting for one percent or more of the variation, explained 31 percent of the total soil K variation.

$$\begin{aligned}\text{Soil K} = 163 &+ 0.024\ (\text{Soil Ca}) - 28.05\ (\text{Soil pH}) \\ &- 0.062\ (\text{Soil Si, Modified Truog}) \\ &+ 0.25\ (\text{Soil Mg}) + 4.11\ (\text{Soil Si, Water}) \\ &- 0.016\ (\text{Soil P}) \qquad (4)\end{aligned}$$

Since pH and soil K are positively correlated (Appendix B, Table 44), the relationship between soil Ca and pH discussed above is probably applicable here, also. Equation (4) indicates that the assumptions originally made in this thesis concerning the factors affecting soil K are basically correct. The factors associated with plant and soil K may affect other bases similarly. For example soil Mg was found to be related to Ca by the equation:

$$\text{Soil Mg} = 14.85 + 0.009\ (\text{Soil Ca}) \qquad (5)$$

This relationship explainsd 69 percent of the variation in soil Mg, and no other soil factor accounted for more than one percent of the variation. When soil Mg was compared with all preharvest factors 83 percent of the variation was accounted for by soil Ca and K and sheath Mg and Ca (8 months). All plant Mg variables were found to closely reflect the soil values.

Sheath Mn was found to be inversely related to sheath moisture, TCA Si, sheath P, K and Mg, whole plant Ca and Mg, soil pH, and modified Truog extractable Si by simple correlation analysis. These inverse relationships are apparently due to the effect of pH as related to the other factors as Mn is known to precipitate from solution with increasing pH.

Aluminum. Soil Al was found to be negatively associated with soil pH, Si (modified Truog), K, Ca, and Mg as well as sheath P and Ca. These relationships are reasonable since calcium carbonate and calcium silicate were added to attain specified levels of soil pH. This pH increase resulted in a decrease in Al activity in the soil solution which in turn allowed increasing amounts of P, K and Mg to become available.

Plant Al was not correlated with soil Al or with any other soil or plant variables except percent dry matter at harvest. Sheath Al, however, was significantly increased by Si and P treatments and increased slightly by pH treatments. These data support the conclusion that Al was the actual causal agent mentioned above.

SUMMARY AND CONCLUSIONS

A ratoon crop of sugarcane, variety H53-263, was grown for 9 months in the field on a Typic Gibbsihumox to study the effects of residual Si and P treatments and soil pH on cane yield and nutrient uptake. The experiment was a complete factorial installed in a split-plot design. No additional nutrients were applied except 112 kg per ha N. Soil and plant analyses were performed to study the effect of mineral composition on cane yield.

Cane yield was significantly increased by residual Si and tended to increase with residual P treatments. Although soil pH had no direct influence on yield, it affected other nutrients which in turn influenced yield. Some of the more important nutrients affected were Ca, Si, Al, K, Mg, and P.

Both plant and soil Si increased significantly with increasing residual Si treatment. However, TCA extractable sheath Si was more closely related to yield than was total sheath Si or soil Si and water extractable soil Si was more closely associated with yield than was modified Truog extractable Si. There was a linear relationship between sheath Si (nine months) and water extractable soil Si ($r = 0.82$).

Residual P treatments significantly increased soil and plant P levels and also had a tendency to increase yields. Phosphorus uptake was found to increase with residual Si treatment; also at a particular sheath P level increased yields were associated with increasing residual Si treatment. Soil and plant K levels were found to be a function of soil Ca, through the complimentary ion effect - of soil pH, due to the pH dependent charge, and of the previous crop yield, through K uptake. Sheath Mg levels were also related to the same factors and were near deficiency levels. However, Mg apparently did not limit growth.

Soil Al was decreased by increasing pH as expected, but was further decreased by increasing Si application at a given pH. Sheath Al was found to increase with increasing Si levels.

Multiple regression analyses were run to help interpret interrelationships between yield, soil factors, and plant factors. The 25 factors measured in the plant crop accounted for only 59 percent of the yield variation while the 48 factors measured in the ratoon crop accounted for 73 percent of the yield variation. In the plant crop, applied factors accounted for most of the yield variation while in the ratoon crop, plant factors accounted for the majority of the variation and residual Si, which explained only 6 percent of the variation, was the only significant applied factor.

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APPENDIX A

ANALYTICAL METHODS

Plant Analytical Methods

Extraction and Digestion Procedures

TCA Extractable Silicon. Soluble Si was extracted from fresh sheaths by the TCA (trichloro-acetic acid) method of Fox *et al*. (1967):

> A 10 g sample of freshly chopped sheath material (1 cm length) and 100 ml 2% TCA solution are homogenized at high speed for 10 minutes in a Waring blender. Filter the extract through Whatman No. 42 filter paper and collect in a plastic vial. Extract the sheaths between 1.5-2.0 hours after sampling. Store the filtrate in a refrigerator until analyzing it by a modification of the Silico-Molybdate Blue method of Kilmer (1965).

Lithium Tetra-Borate Fusion. A modification of the lithium tetra-borate method of Suhr and Ingamells (1966) was used for the fusion of ashed plant material for Si determination:

> Place a 0.5 g sample of ground plant material in a platinum crucible and ash overnight at 550°C in a muffle furnace. After cooling, thoroughly mix 0.5 g lithium tetraborate with the ash and quantitatively transfer the mixture to a carbon crucible. Fuse the sample in a muffle furnace at 950°C for 15 minutes. Remove the crucible from the furnace, swirl it to gather uncoalesced beads of molten material, and pour the hot melt into 100 ml 0.5 N nitric acid. Stir the nitric acid solution with a magnetic stirrer until the melt is completely dissolved. Determine Si in the solution using the Silico-Molybdate Blue method (Kilmer 1965).

Nitric-Perchloric Acid Digest. Plant P, K, Ca, Mg, Mn and Al were determined on the nitric-perchloric acid digest of the plant material (Jackson, 1958):

> Place 1.0 g dried plant material in a 100 ml Kjeldahl digestion flask. Add 15 ml 2:1 nitric:perchloric acid solution making sure that all plant material is contained in the acid solution. Cover the flask with an inverted beaker and allow mixture to predigest overnight. Digest in a microkjeldahl rack until the white fuming stage is reached and continue the digestion at low heat for 15 minutes to complete dehydration of the Si. Cool the mixture to room temperature, transfer to a 50 ml. volumetric flask and make to volume.

Chemical Methods

Plant Silicon. Plant Si was determined by the Silico-Molybdate Blue method of Kilmer (1965):

> Transfer an aliquot of sample solution to a 50 ml volumetric flask. Dilute to about 35 ml. Add 1 ml ammonium molybdate solution, mix and let stand for 30 minutes. Add 3 ml 10% oxalic acid solution and mix. Within 2 minutes add 1 ml reducing solution, mix and make to volume. Allow 30 minutes for color development and determine optical density at 660 m on a spectrophotometer.

TCA extractable Si was determined in the same manner; however 5 ml of 10 percent ammonium persulfate solution was added prior to the molybdate addition to prevent premature reduction of the molybdate yellow complex to the blue complex.

Plant Phosphorus. Plant P was determined by the Vandate-Molybdate Yellow method of Barton (1948):

> Transfer a 5 ml aliquot of sample solution to a 50 ml volumetric flask. Dilute to about 30 ml. Add 5 ml Barton's reagent, mix, dilute to volume and mix again. After 30 minutes read optical density at 430 m on a spectrophotometer.

Plant Nitrogen. Plant N was determined by the Kjeldahl method:

> Weigh out 3 g dry tissue and place in an 800 ml Kjeldahl flask; add 30 ml concentrated sulfuric acid, 5 g sodium sulfate, 5 drops selenium oxychloride and several glass beads. Digest until the solution clears and then continue digestion for 30 minutes. Cool, dilute digest with about 300 ml water and cool to 35°C. Carefully pour 90-100 ml 50 percent sodium hydroxide down the side of the flask to avoid mixing. Add a few pieces of mossy zinc and attach to distillation unit immediately. Turn on heat and mix contents by shaking rapidly. Distill about 200 ml into 50 ml boric acid solution. Titrate with standard acid.

Soil Analytical Methods

Extraction Methods

Water Extractable Silica. Soil Si was extracted by shaking 10 g soil (oven dry basis) with 100 ml water for 4 hours and filtering through Whatman No. 42 filter paper. Soil Si was also extracted with the modified Truog extractant as described below for soil P. In both cases Si was determined by the Silico-Molybdate method of Kilmer (1965).

Modified Truog Extractable Phosphorus. Soil P was extracted by the modified Truog method of Ayres and Hagihara (1952):

> To a 1.5 g soil sample (oven dry basis) in a 200 ml flask, add 150 ml 0.02 N sulfuric acid (containing 3 g/l ammonium sulfate) and shake for 30 minutes. The extract is filtered through Whatman No. 42 filter paper. Determine P by the Molybdenum Blue method of Dickman and Bray (1940).

Exchangeable Bases. Exchangeable K, Ca and Mg were extracted with N ammonium acetate (pH 7.0).

> Combine 10 g soil (oven dry basis) with 100 ml N ammonium acetate (pH 7.0) and shake for 15 minutes. Allow the suspension to equilibrate overnight and again shake 15 minutes. Filter the suspension through Whatman No. 42 filter paper. Transfer all the soil to the filter paper and wash it 3 times with 30 ml ammonium acetate solution. Make the resulting filtrate to 200 ml volume with ammonium acetate solution. Determine bases on an atomic absorption spectrophotometer.

Extractable Soil Aluminum. Soil Al was extracted by shaking 10 g soil (oven dry basis) with 100 ml N potassium chloride for 30 minutes and centrifuging the suspension to obtain a clear extract. Aluminum was then determined by the Aluminon method of Chenery (1948).

Chemical Methods

Soil Phosphorus. Soil P was determined by the Molybdenum Blue method of Dickman and Bray (1940):

> Transfer a 10 ml aliquot of soil extract to a 50 ml volumetric flask. Dilute to about 30 ml and add 10 ml dilute stannous chloride solution. Dilute to volume and mix. After 10 minutes read optical density at 660 m on a spectrophotometer.

<u>Soil Silicon</u>. Soil Si was determined by the Silico-Molybdate Blue method of Kilmer (1965) as described previously.

<u>Soil Aluminum</u>. Soil Al was determined by the Aluminon method of Chenery (1948):

> Transfer a 10 ml aliquot of soil extract to a 50 ml volumetric flask. Dilute to about 20 ml and add 2 ml 1 percent thioglycollic acid. Mix and add 10 ml aluminon reagent and mix again. Transfer the solution to a 100 ml beaker, adjust the pH of the solution to 4.2 with 1:1 ammonium hydroxide or 1:1 hydrochloric acid and return the solution to the 50 ml flask with 2 or 3 small distilled water washes. Heat in a steam bath for 16 minutes, cool 2 hours and dilute to volume. Mix and read optical density at 537.5 m on a spectrophotometer.

Table 20. Dilutions to Make for Analysis of Sugarcane Sheath Samples by Atomic Absorption Spectrophotometry*

Element	Cane Grown in Nutrient Soil	Cane Grown in Soil	Optimum Range**	Remarks
Al	10	10	10-200 ppm	
Ca	2,000	1,000	1- 10	Add 0.5% LaO
Cu	10	10	.5- 10	
Fe	10	10	2- 20	
K	200	200	1- 10	
Mg	2,000	1,000	.2- 2	Add 0.5% LaO
Mn	10	10	2- 20	
Si	10	10	50-500	
Zn	10	10	.2- 2	

*Values are expressed as $\frac{\text{final volume of solution}}{\text{sample weight (oven dry)}}$.

**NOTE: Flame can be turned sideways so that solutions 10 times more concentrated than those indicated may be determined.

APPENDIX B

Table 21. Influence of Si, P and pH Treatments on Yield of Sugarcane (Ratoon Crop) Harvested at Nine Months[1/]

Si x P x pH[2/]

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 P (kg/ha) 280	pH 5.5 P (kg/ha) 1120	pH 5.8 P (kg/ha) 112	pH 5.8 P (kg/ha) 280	pH 5.8 P (kg/ha) 1120	pH 6.5 P (kg/ha) 112	pH 6.5 P (kg/ha) 280	pH 6.5 P (kg/ha) 1120	pH 5.0 P (kg/ha) 112	pH 5.0 P (kg/ha) 280	pH 5.0 P (kg/ha) 1120	pH 6.0 P (kg/ha) 0
0	107.1	118.3	118.9	108.7	106.2	106.6	119.6	120.5	121.6				91.2
833	103.0	131.9	113.6	134.4	118.7	123.4	119.2	120.5	120.5	127.0	137.8	118.5	125.0
1666	137.1	126.3	144.9	106.8	122.7	108.4	126.1	123.0	135.1				111.1

Si x pH[3/]

Si (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
0	114.7	107.3	120.5	114.2
833	116.2	125.4	120.1	120.5
1666	136.2	112.7	128.1	125.7
AVG.	122.3	115.1	123.0	120.1

Si x P[3/]

Si (kg/ha)	P (kg/ha) 112	P (kg/ha) 280	P (kg/ha) 1120	AVG.
0	111.8	114.9	115.8	114.2
833	118.9	123.6	119.2	120.5
1666	123.4	124.1	129.5	125.7
AVG.	118.0	121.0	121.4	120.1

P x pH[3/]

P (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
112	115.8	116.7	121.6	118.0
280	125.4	115.8	121.4	121.0
1120	125.9	112.7	125.7	121.4
AVG.	122.3	115.1	123.0	120.1

Control Plot 49.1

[1/] Tons (metric)/hectare.

[2/] Means of 3 observations.

[3/] Means of 9 observations.

Table 22. Influence of Si, P and pH Treatments on Soil pH (Sampled on 15 July 1968)[1/]

Si x P x pH[2/]

Si (kg/ha)	pH 5.5			pH 5.8			pH 6.5			pH 5.0			pH 6.0
	P (kg/ha)			P (kg/ha)			P (kg/ha)			P (kg/ha)			P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	5.26	5.41	5.41	5.59	5.66	5.70	6.18	6.43	6.45				5.85
833	5.57	5.45	5.62	5.75	5.75	5.85	6.43	6.66	6.43	5.51	5.39	5.46	5.50
1666	5.42	5.54	5.46	5.72	5.80	5.83	6.66	6.44	6.56				6.08

Si x pH[3/]

Si (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
0	5.36	5.65	6.35	5.79
833	5.55	5.78	6.51	5.95
1666	5.47	5.78	6.56	5.94
AVG.	5.46	5.74	6.47	

Si x P[3/]

Si (kg/ha)	P (kg/ha) 5.5	5.8	6.5	AVG.
0	5.68	5.83	5.85	5.79
833	5.92	5.95	5.96	5.95
1666	5.94	5.93	5.95	5.94
AVG.	5.84	5.90	5.92	

P x pH[3/]

P (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
112	5.42	5.69	6.42	5.84
280	5.46	5.74	6.51	5.90
1120	5.50	5.78	6.48	5.92
AVG.	5.46	5.74	6.47	

Control Plot 5.29

[1/] 1:2.5 soil:water suspension.

[2/] Means of 3 observations.

[3/] Means of 9 observations.

Table 23. Influence of Si, P and pH Treatments on Water-Extractable Soil Si (Sampled on 15 July 1958)[1/]

Si x P x pH[2/]

Si (kg/ha)	pH 5.5 P (kg/ha) 112	280	1120	pH 5.8 P (kg/ha) 112	280	1120	pH 6.5 P (kg/ha) 112	280	1120	pH 5.0 P (kg/ha) 112	280	1120	pH 6.0 P (kg/ha) 0
0	0.49	0.62	0.58	0.50	0.46	0.68	0.41	0.43	0.57				0.49
833	1.31	1.51	1.51	1.34	1.18	1.29	0.97	0.97	0.90	1.26	1.12	1.12	1.12
1666	2.31	2.21	2.15	1.95	1.78	1.88	1.32	1.44	1.53				1.12

Si x pH[3/]

Si (kg/ha)	pH 5.5	5.8	6.5	AVG.
0	0.56	0.55	0.47	0.53
833	1.44	1.27	0.95	1.22
1666	2.22	1.87	1.43	1.84
AVG.	1.41	1.23	0.95	

Si x P[3/]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	0.47	0.50	0.61	0.53
833	1.21	1.22	1.23	1.22
1666	1.86	1.81	1.85	1.84
AVG.	1.18	1.18	1.23	

P x pH[3/]

P (kg/ha)	pH 5.5	5.8	6.5	AVG.
112	1.37	1.27	0.90	1.18
280	1.45	1.14	0.95	1.18
1120	1.41	1.28	1.00	1.23
AVG.	1.41	1.23	0.95	

Control Plot 0.50

[1/] Expressed as ppm Si in 1:10 soil:water extract.

[2/] Means of 3 observations.

[3/] Means of 9 observations.

Table 24. Influence of Si, P and pH Treatments on Modified Truog-Extractable Soil Si (Sampled on 15 July 1968)[1/]

Si x P x pH[2/]

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 5.8 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	39.8	44.1	34.5	40.1	37.8	52.7	52.4	57.6	62.5				43.9
833	106.1	99.0	81.7	128.9	94.9	95.7	145.9	167.0	132.5	176.7	95.4	83.1	115.7
1666	164.8	167.0	135.4	163 5	145.4	126.7	230.9	220.0	258.3				173.3

Si x pH[3/]

Si (kg/ha)	pH 5.5	5.8	6.5	AVG.
0	39.5	43.5	57.5	46.8
833	95.6	106.5	148.5	116.9
1666	155.7	145.2	236.4	179.1
AVG.	96.9	98.4	147.5	

Si x P[3/]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	44.1	46.5	49.9	46.8
833	127.0	120.3	103.3	116.9
1666	186.4	177.5	173.4	179.1
AVG.	119.2	114.8	108.9	

P x pH[3/]

P (kg/ha)	pH 5.5	5.8	6.5	AVG.
112	103.6	110.8	143.1	119.2
280	103.4	92.7	148.2	114.8
1120	83.8	91.7	151.1	108.9
AVG.	96.9	98.4	147.5	

Control Plot 346

[1/] Expressed as ppm Si.

[2/] Means of 3 observations.

[3/] Means of 9 observations.

Table 25. Influence of Si, P and pH Treatments on TCA-Extractable Si in Sugarcane Sheaths Sampled at Nine Months[1/]

Si x P x pH[2/]

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 5.8 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	32.1	31.3	26.1	20.3	21.9	33.7	27.5	25.3	28.9				29.4
833	43.1	44.1	39.4	37.4	40.7	41.0	31.1	29.8	25.2	47.8	47.6	41.0	40.1
1666	52.4	57.3	43.6	37.6	39.4	41.2	40.6	33.2	35.0				48.3

Si x pH[3/]

Si (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
0	29.8	25.3	27.2	27.4
833	42.2	39.7	28.7	36.9
1666	51.1	39.4	36.3	42.3
AVG.	41.0	34.8	30.7	

Si x P[3/]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	26.6	26.2	29.6	27.4
833	37.2	38.2	35.2	36.9
1666	43.5	43.3	39.9	42.3
AVG.	35.8	35.9	34.9	35.5

P x pH[3/]

P (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
112	42.5	31.8	33.1	35.8
280	44.2	34.0	29.4	35.9
1120	36.4	38.6	29.7	34.9
AVG.	41.0	34.8	30.7	

Control Plot 23.9

[1/] Data expressed as ppm Si (fresh weight basis).

[2/] Means of 3 observations.

[3/] Means of 9 observations.

Table 26. Influence of Si, P and pH Treatments on Si in Sugarcane Sheaths Sampled at Nine Months[1]

Si x P x pH[2]

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 280	pH 5.5 1120	pH 5.8 P (kg/ha) 112	pH 5.8 280	pH 5.8 1120	pH 6.5 P (kg/ha) 112	pH 6.5 280	pH 6.5 1120	pH 5.0 P (kg/ha) 112	pH 5.0 280	pH 5.0 1120	pH 6.0 P (kg/ha) 0
0	2278	2444	2413	1975	1907	3025	2146	2418	2302				2151
833	4070	3976	3656	3986	4305	4546	3150	3150	2928	4325	4131	3728	3849
1666	5417	5846	4829	4377	4835	5030	4636	4044	4820				5270

Si x pH[3]

Si (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
0	2382	2303	2289	2324
833	3901	4279	3075	3752
1666	5364	4747	4500	4871
AVG.	3882	3777	3288	

Si x P[3]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	2136	2257	2580	2324
833	3735	3811	3710	3752
1666	4810	4909	4893	4871
AVG.	3560	3659	3728	

P x pH[3]

P (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
112	3925	3446	3310	3560
280	4089	3683	3204	3659
1120	3633	4200	3350	3728
AVG.	3882	3777	3288	

[1] Expressed as ppm Si.

[2] Means of 3 observations.

[3] Means of 9 observations.

Table 27. Influence of Si, P and pH Treatments on Whole Plant Si in Sugarcane Sampled at Nine Months[1/]

Si x P x pH[2/]

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 P (kg/ha) 280	pH 5.5 P (kg/ha) 1120	pH 5.8 P (kg/ha) 112	pH 5.8 P (kg/ha) 280	pH 5.8 P (kg/ha) 1120	pH 6.5 P (kg/ha) 112	pH 6.5 P (kg/ha) 280	pH 6.5 P (kg/ha) 1120	pH 5.0 P (kg/ha) 112	pH 5.0 P (kg/ha) 280	pH 5.0 P (kg/ha) 1120	pH 6.0 P (kg/ha) 0
0	973	826	1228	787	792	1098	956	894	854				928
833	1884	1975	1992	1652	1606	1601	1460	1584	1307	2309	1850	2133	1658
1666	3367	3390	4814	2326	2761	2946	2179	2360	1952				3005

Si x pH[3/]

Si (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
0	1009	892	902	934
833	1950	1620	1450	1674
1666	3857	2671	2164	2897
AVG.	2272	1728	1505	

Si x P[3/]

Si (kg/ha)	P (kg/ha) 112	P (kg/ha) 280	P (kg/ha) 1120	AVG.
0	905	837	1060	934
833	1666	1722	1633	1674
1666	2624	2837	3231	2897
AVG.	1732	1799	1975	

P x pH[3/]

P (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
112	2075	1588	1532	1732
280	2034	1720	1613	1799
1120	2678	1875	1371	1975
AVG.	2272	1728	1505	

Control Plot 1069

[1/] Expressed as ppm Si.

[2/] Means of 3 observations.

[3/] Means of 9 observations.

Table 28. Influence of Si, P and pH Treatments on Si Uptake in Sugarcane Sampled at Nine Months[1/]

Si x P x pH[2/]

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 5.8 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	24.6	25.1	38.8	23.2	21.6	29.5	30.6	29.2	29.2				20.9
833	48.7	63.8	59.1	57.2	50.1	54.0	46.8	62.4	39.3	81.2	62.2	64.1	54.3
1666	121.0	123.1	140.7	59.4	88.1	85.1	75.5	79.5	76.1				83.6

Si x pH[3/]

Si (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
0	29.5	24.8	29.7	28.0
833	57.2	53.8	49.5	53.5
1666	128.3	77.5	77.0	94.3
AVG.	71.7	52.0	52.1	

Si x P[3/]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	26.1	25.3	32.5	28.0
833	50.9	58.8	50.8	53.5
1666	85.3	96.9	100.6	94.3
AVG.	54.1	60.3	61.3	

P x pH[3/]

P (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG
112	64.8	46.6	51.0	54.1
280	70.7	53.3	57.0	60.3
1120	79.5	56.2	48.2	61.3
AVG.	71.7	52.0	52.1	

Control Plot 13.0

[1/] Expressed as kg/ha Si.

[2/] Means of 3 observations.

[3/] Means of 9 observations.

Table 29. Influence of Si, P and pH Treatments on Modified Truog-Extractable Soil P (Sampled on 15 July 1968)1/

Si x P x pH2/

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 5.8 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	32.4	59.2	186.8	30.5	50.4	186.8	26.4	63.8	218.3				29.1
833	35.9	65.1	244.9	30.0	62.7	209.0	48.0	88.4	176.0	31.1	71.1	230.4	36.1
1666	39.3	69.6	190.9	38.3	64.4	242.1	47.3	66.8	277.3				25.5

Si x pH3/

Si (kg/ha)	pH 5.5	5.8	6.5	AVG.
0	92.8	88.7	102.8	94.8
833	115.3	100.6	104.1	106.7
1666	100.0	114.9	130.5	115.1
AVG.	102.7	101.4	112.5	

Si x P3/

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	29.8	57.8	196.7	94.8
833	38.0	72.1	210.0	106.7
1666	41.7	66.9	236.8	115.1
AVG.	36.5	65.6	214.5	

P x pH3/

P (kg/ha)	pH 5.5	5.8	6.5	AVG.
112	35.9	33.0	40.6	36.5
280	64.6	59.2	73.0	65.6
1120	207.5	212.1	223.9	214.5
AVG.	102.7	101.4	112.5	

Control Plot 130

1/ Expressed as ppm P.

2/ Means of 3 observations.

3/ Means of 9 observations.

Table 30. Influence of Si, P and pH Treatments on P in Sugarcane Sheaths Sampled at Nine Months[1]

Si x P x pH[2]

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 5.8 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	636	855	909	624	758	1139	727	872	1091				1224
833	672	691	994	666	740	1054	752	764	958	654	685	806	686
1666	691	885	921	594	733	1187	849	721	1066				600

Si x pH[3]

Si (kg/ha)	pH 5.5	5.8	6.5	AVG.
0	800	840	897	846
833	786	820	825	810
1666	832	838	879	850
AVG.	806	833	867	

Si x P[3]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	662	828	1046	846
833	697	732	1002	810
1666	711	780	1058	850
AVG.	690	780	1069	

P x pH[3]

P (kg/ha)	pH 5.5	5.8	6.5	AVG.
112	666	628	776	690
280	810	744	786	780
1120	941	1127	1038	1069
AVG.	806	833	867	

Control Plot 400

[1] Data expressed as ppm P.

[2] Means of 3 observations.

[3] Means of 9 observations.

Table 31. Influence of Si, P and pH Treatments on Whole Plant P in Sugarcane Sampled at Nine Months[1]

Si x P x pH[2]

Si (kg/ha)	pH 5.5 P (kg/ha) 112	280	1120	pH 5.8 P (kg/ha) 112	280	1120	pH 6.5 P (kg/ha) 112	280	1120	pH 5.0 P (kg/ha) 112	280	1120	pH 6.0 P (kg/ha) 0
0	571	656	838	559	584	814	571	717	826				510
833	595	638	826	480	565	778	590	753	850	480	553	693	456
1666	565	641	915	559	620	911	620	589	759				529

Si x pH[3]

Si (kg/ha)	pH 5.5	5.8	6.5	AVG.
0	689	652	705	682
833	687	608	731	675
1666	707	697	656	687
AVG.	694	652	697	

Si x P[3]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	567	652	826	682
833	555	652	818	675
1666	581	617	862	687
AVG.	568	640	835	

P x pH[3]

P (kg/ha)	pH 5.5	5.8	6.5	AVG.
112	577	533	593	568
280	645	589	687	640
1120	860	834	812	835
AVG.	694	652	697	

Control Plot 529

[1] Expressed as ppm P.

[2] Means of 3 observations.

[3] Means of 9 observations.

Table 32. Influence of Si, P and pH Treatments on P Uptake by Sugarcane Sampled at Nine Months[1]

Si x P x pH[2]

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 5.8 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	1.47	2.03	2.61	1.66	1.61	2.28	1.80	2.18	2.80				1.14
833	1.51	2.06	2.45	1.66	1.76	2.60	1.88	2.48	2.52	1.69	1.88	2.07	1.47
1666	1.99	2.32	2.66	1.41	1.97	2.65	2.13	2.00	2.95				1.47

Si x pH[3]

Si (kg/ha)	pH 5.5	5.8	6.5	AVG.
0	2.04	1.85	2.26	2.04
833	2.01	2.01	2.29	2.10
1666	2.32	2.01	2.36	2.23
AVG.	2.12	1.96	2.30	

Si x P[3]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	1.64	1.94	2.56	2.04
833	1.68	2.10	2.52	2.10
1666	1.84	2.10	2.75	2.23
AVG.	1.72	2.05	2.61	

P x pH[3]

P (kg/ha)	pH 5.5	5.8	6.5	AVG.
112	1.66	1.58	1.94	1.72
280	2.14	1.78	2.22	2.05
1120	2.57	2.51	2.76	2.61
AVG.	2.12	1.96	2.30	

Control Plot 0.64

[1] Expressed as kg/ha P x 10^{-1}.

[2] Means of 3 observations.

[3] Means of 9 observations.

Table 33. Influence of Si, P and pH Treatments on Whole Plant N in Sugarcane Sampled at Nine Months[1/]

Si x P x pH[2/]

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 280	pH 5.5 1120	pH 5.8 P (kg/ha) 112	pH 5.8 280	pH 5.8 1120	pH 6.5 P (kg/ha) 112	pH 6.5 280	pH 6.5 1120	pH 5.0 P (kg/ha) 112	pH 5.0 280	pH 5.0 1120	pH 6.0 P (kg/ha) 0
0	4658	4522	4856	4391	3931	4920	4453	4533	5020				4188
833	4432	4753	3816	3541	3705	3867	4233	5325	4939	3798	3934	3726	4142
1666	4155	4448	5202	4154	3610	4006	3784	4360	4241				3895

Si x pH[3/]

Si (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
0	4678	4414	4669	4587
833	4334	3704	4832	4290
1666	4602	3923	4128	4218
AVG.	4538	4014	4543	

Si x P[3/]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	4501	4329	4923	4587
833	4069	4595	4207	4290
1666	4031	4139	4483	4218
AVG.	4200	4354	4541	

P x pH[3/]

P (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
112	4415	4029	4157	4200
280	4574	3749	4739	4354
1120	4625	4264	4733	4541
AVG.	4538	4014	4543	

Control Plot 6049

1/ Expressed as ppm N.

2/ Means of 3 observations.

3/ Means of 9 observations.

Table 34. Influence of Si, P and pH Treatments on N NH_4Ac Extractable Soil K (Sampled on 15 July 1968)[1/]

Si x P x pH[2/]

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 5.8 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	30.1	33.1	28.8	27.5	25.9	43.1	26.1	43.7	33.1				31.9
833	28.2	36.6	36.5	34.7	30.4	32.6	44.5	37.7	35.2	30.5	30.3	36.6	44.0
1666	31.3	32.1	22.6	31.7	30.6	29.7	39.4	37.5	45.4				34.4

Si x pH[3/]

Si (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
0	30.7	32.2	34.3	32.4
833	33.8	32.6	39.1	35.2
1666	28.7	30.7	40.8	33.4
AVG.	31.0	31.8	38.1	

Si x P[3/]

Si (kg/ha)	P (kg/ha) 112	P (kg/ha) 280	P (kg/ha) 1120	AVG.
0	27.9	34.2	35.0	32.4
833	35.8	34.9	34.8	35.2
1666	34.1	33.4	32.6	33.4
AVG.	32.6	34.2	34.1	

P x pH[3/]

P (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
112	29.9	31.3	36.7	32.6
280	33.9	29.0	39.6	34.2
1120	29.3	35.1	37.9	34.1
AVG.	31.0	31.8	38.1	

Control Plot 46.0

[1/] Expressed as ppm K.

[2/] Means of 3 observations.

[3/] Means of 9 observations.

Table 35. Influence of Si, P and pH Treatments on K in Sugarcane Sheaths Sampled at Nine Months[1]

Si x P x pH[2]

Si (kg/ha)	pH 5.5 P (kg/ha) 112	280	1120	pH 5.8 P (kg/ha) 112	280	1120	pH 6.5 P (kg/ha) 112	280	1120	pH 5.0 P (kg/ha) 112	280	1120	pH 6.0 P (kg/ha) 0
0	1.45	1.24	1.18	1.14	1.54	1.34	1.55	1.49	1.44				1.88
833	1.20	1.21	1.21	1.52	1.38	1.21	2.02	1.64	1.50	1.42	1.67	1.35	1.61
1666	1.68	1.15	1.54	1.51	1.40	1.29	1.61	1.43	1.33				1.46

Si x pH[3]

Si (kg/ha)	pH 5.5	5.8	6.5	AVG.
0	1.29	1.34	1.49	1.37
833	1.21	1.37	1.72	1.43
1666	1.46	1.40	1.46	1.44
AVG.	1.32	1.37	1.56	

Si x P[3]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	1.38	1.42	1.32	1.37
833	1.58	1.41	1.31	1.43
1666	1.60	1.33	1.39	1.44
AVG.	1.52	1.39	1.34	1.42

P x pH[3]

P (kg/ha)	pH 5.5	5.8	6.5	AVG.
112	1.44	1.39	1.73	1.52
280	1.20	1.44	1.52	1.39
1120	1.31	1.28	1.42	1.34
AVG.	1.32	1.37	1.56	

Control Plot 1.17

[1] Expressed as % K.

[2] Means of 3 observations.

[3] Means of 9 observations.

Table 36. Influence of Si, P and pH Treatments on N NH_4Ac Extractable Soil Ca (Sampled on 15 July 1968)1/

Si x P x pH2/

Si (kg/ha)	pH 5.5 P (kg/ha) 112	280	1120	pH 5.8 P (kg/ha) 112	280	1120	pH 6.5 P (kg/ha) 112	280	1120	pH 5.0 P (kg/ha) 112	280	1120	pH 6.0 P (kg/ha) 0
0	433	721	649	756	762	1090	1794	2293	2261				786
833	684	650	909	1096	1035	1244	2256	2438	2238	549	559	787	985
1666	856	913	851	1136	1062	1262	2646	2226	2808				1270

Si x pH3/

Si (kg/ha)	pH 5.5	5.8	6.5	AVG.
0	601	869	2116	1196
833	748	1125	2311	1394
1666	873	1153	2560	1529
AVG.	741	1049	2329	

Si x P3/

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	994	1259	1333	1196
833	1345	1374	1464	1394
1666	1546	1401	1640	1529
AVG.	1295	1345	1479	

P x pH3/

P (kg/ha)	pH 5.5	5.8	6.5	AVG.
112	658	996	2232	1295
280	762	953	2319	1345
1120	803	1199	2435	1479
AVG.	741	1049	2329	

Control Plot 110

1/ Expressed as ppm Ca.

2/ Means of 3 observations.

3/ Means of 9 observations.

Table 37. Influence of Si, P and pH Treatments on Ca in Sugarcane Sheaths Sampled at Nine Months[1]

Si x P x pH[2]

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 5.8 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	.312	.324	.334	.356	.308	.359	.399	.388	.366				.282
833	.345	.328	.317	.324	.346	.339	.352	.366	.395	.316	.260	.293	.304
1666	.283	.372	.312	.325	.313	.342	.369	.369	.407				.310

Si x pH[3]

Si (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
0	.3233	.3411	.3840	.3495
833	.3297	.3365	.3710	.3457
1666	.3224	.3268	.3818	.3437
AVG.	.3251	.3348	.3789	

Si x P[3]

Si (kg/ha)	P (kg/ha) 112	P (kg/ha) 280	P (kg/ha) 1120	AVG.
0	.3556	.3398	.3531	.3495
833	.3402	.3467	.3503	.3457
1666	.3258	.3512	.3539	.3437
AVG.	.3405	.3459	.3524	

P x pH[3]

P (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
112	.3133	.3350	.3733	.3405
280	.3411	.3225	.3741	.3459
1120	.3210	.3468	.3895	.3524
AVG.	.3251	.3348	.3789	

Control Plot .118

1/ Expressed as % Ca.

2/ Means of 3 observations.

3/ Means of 9 observations.

Table 38. Influence of Si, P and pH Treatments on N NH_4Ac Extractable Soil Mg (Sampled on 15 July 1968)[1]

Si x P x pH[2]

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 P (kg/ha) 280	pH 5.5 P (kg/ha) 1120	pH 5.8 P (kg/ha) 112	pH 5.8 P (kg/ha) 280	pH 5.8 P (kg/ha) 1120	pH 6.5 P (kg/ha) 112	pH 6.5 P (kg/ha) 280	pH 6.5 P (kg/ha) 1120	pH 5.0 P (kg/ha) 112	pH 5.0 P (kg/ha) 280	pH 5.0 P (kg/ha) 1120	pH 6.0 P (kg/ha) 0
0	19.9	24.1	22.5	22.0	20.0	26.2	29.2	37.0	36.7				26.9
833	24.1	17.9	24.9	25.5	25.8	26.6	39.3	32.0	34.5	19.3	19.2	21.5	28.5
1666	24.7	24.5	20.9	24.0	23.3	21.3	38.6	34.7	36.8				27.4

Si x pH[3]

Si (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
0	22.2	22.7	34.3	26.4
833	22.3	26.0	35.3	27.9
1666	23.4	22.9	36.7	27.7
AVG.	22.6	23.9	35.4	

Si x P[3]

Si (kg/ha)	P (kg/ha) 112	P (kg/ha) 280	P (kg/ha) 1120	AVG.
0	23.7	27.0	28.5	26.4
833	29.6	25.3	28.7	27.9
1666	29.1	27.5	26.4	27.7
AVG.	27.5	26.6	27.8	

P x pH[3]

P (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
112	22.9	23.8	35.7	27.5
280	22.2	23.0	34.6	26.6
1120	22.8	24.7	36.0	27.8
AVG.	22.6	23.9	35.4	

[1] Expressed as ppm Mg.

[2] Means of 3 observations.

[3] Means of 9 observations.

Table 39. Influence of Si, P and pH Treatments on Mg in Sugarcane Sheaths Sampled at Nine Months[1/]

Si x P x pH[2/]

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 5.8 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	964	1041	929	1211	781	1134	1133	1047	933				881
833	1147	813	798	787	945	1021	876	874	1005	876	864	938	895
1666	886	979	720	857	891	800	1036	881	917				922

Si x pH[3/]

Si (kg/ha)	pH 5.5	5.8	6.5	AVG.
0	978	1042	1038	1019
833	919	918	918	918
1666	862	849	945	885
AVG.	920	936	967	

Si x P[3/]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	1102	956	999	1019
833	937	877	941	918
1666	926	917	812	885
AVG.	988	917	917	

P x pH[3/]

P (kg/ha)	pH 5.5	6.0	6.5	AVG.
112	999	952	1015	988
280	945	872	934	917
1120	816	985	952	917
AVG.	920	936	967	

Control Plot 798

1/ Expressed as ppm Mg.

2/ Means of 3 observations.

3/ Means of 9 observations.

Table 40. Influence of Si, P and pH Treatments on Mn in Sugarcane Sheaths Sampled at Nine Months[1]

Si x P x pH[2]

Si (kg/ha)	pH 5.5 P (kg/ha) 112	280	1120	pH 5.8 P (kg/ha) 112	280	1120	pH 6.5 P (kg/ha) 112	280	1120	pH 5.0 P (kg/ha) 112	280	1120	pH 6.0 P (kg/ha) 0
0	45.7	53.7	46.3	56.3	44.3	47.3	44.0	35.0	28.7				72.7
833	46.3	56.3	52.0	75.0	69.0	70.0	36.3	39.7	39.0	41.7	47.3	43.7	64.7
1666	46.3	52.0	43.7	42.7	44.3	43.7	26.3	25.3	30.3				76.7

Si x pH[3]

Si (kg/ha)	pH 5.5	5.8	6.5	AVG.
0	48.6	49.3	35.9	44.6
833	51.5	71.3	38.3	53.7
1666	47.3	43.6	27.3	39.4
AVG.	49.1	54.7	33.8	

Si x P[3]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	48.7	44.3	40.8	44.6
833	52.5	55.0	53.7	53.7
1666	38.4	40.5	39.2	39.4
AVG.	46.5	46.6	44.6	45.9

P x pH[3]

P (kg/ha)	pH 5.5	5.8	6.5	AVG.
112	46.1	58.0	35.5	46.5
280	54.0	52.5	33.3	46.6
1120	47.3	53.7	32.7	44.6
AVG.	49.1	54.7	33.8	

Control Plot 63

[1] Data expressed as ppm Mn.

[2] Means of 3 observations.

[3] Means of 9 observations.

Table 41. Influence of Si, P and pH Treatments on N KCl Extractable Soil Al (Sampled on 15 July 1968)[1]

Si x P x pH[2]

Si (kg/ha)	pH 5.5 P (kg/ha)			pH 5.8 P (kg/ha)			pH 6.5 P (kg/ha)			pH 5.0 P (kg/ha)			pH 6.0 P (kg/ha)
	112	280	1120	112	280	1120	112	280	1120	112	280	1120	0
0	27.8	12.5	20.2	8.2	7.9	4.6	0.8	0.2	0.3				7.1
833	10.5	15.7	7.0	2.2	3.1	4.8	0.2	0.3	0.7	12.0	25.7	14.3	2.2
1666	13.6	8.2	14.5	2.7	3.7	2.7	0.2	0.3	0.3				1.0

Si x pH[3]

Si (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
0	20.2	6.9	0.4	9.2
833	11.1	3.4	0.4	4.9
1666	12.1	3.1	0.2	5.1
AVG.	14.4	4.4	0.3	

Si x P[3]

Si (kg/ha)	P (kg/ha) 112	280	1120	AVG.
0	12.2	6.8	8.4	9.2
833	4.3	6.3	4.2	4.9
1666	5.5	4.1	5.8	5.1
AVG.	7.4	5.7	6.1	

P x pH[3]

P (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
112	17.3	4.4	0.4	7.4
280	12.1	4.9	0.2	5.7
1120	13.9	4.1	0.4	6.1
AVG.	14.4	4.4	0.3	

Control Plot 49.0

[1] Expressed as ppm Al.

[2] Means of 3 observations.

[3] Means of 9 observations.

Table 42. Influence of Si, P and pH Treatments on Al in Sugarcane Sheaths Sampled at Nine Months[1/]

Si x P x pH[2/]

Si (kg/ha)	pH 5.5 P (kg/ha) 112	pH 5.5 P (kg/ha) 280	pH 5.5 P (kg/ha) 1120	pH 5.8 P (kg/ha) 112	pH 5.8 P (kg/ha) 280	pH 5.8 P (kg/ha) 1120	pH 6.5 P (kg/ha) 112	pH 6.5 P (kg/ha) 280	pH 6.5 P (kg/ha) 1120	pH 5.0 P (kg/ha) 112	pH 5.0 P (kg/ha) 280	pH 5.0 P (kg/ha) 1120	pH 6.0 P (kg/ha) 0
0	18.3	13.0	11.7	16.3	7.3	16.7	12.3	11.7	11.3				15.7
833	15.7	12.0	14.7	14.3	11.7	12.0	13.0	10.3	16.3	13.3	11.3	9.0	13.3
1666	11.7	8.3	11.3	13.0	13.0	16.0	12.7	14.3	17.0				9.3

Si x pH[3/]

Si (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
0	14.3	13.4	11.8	13.2
833	14.1	12.6	13.2	13.3
1666	10.4	14.0	14.7	13.0
AVG.	13.0	13.4	13.2	

Si x P[3/]

Si (kg/ha)	P (kg/ha) 112	P (kg/ha) 280	P (kg/ha) 1120	AVG.
0	15.7	10.7	13.2	13.2
833	14.3	11.3	14.3	13.3
1666	12.4	11.9	14.8	13.0
AVG.	14.1	11.3	14.1	

P x pH[3/]

P (kg/ha)	pH 5.5	pH 5.8	pH 6.5	AVG.
112	15.2	14.6	12.7	14.1
280	11.1	10.7	12.1	11.3
1120	12.6	14.9	14.9	14.1
AVG.	13.0	13.4	13.2	

Control Plot 6

[1/] Expressed as ppm Al.

[2/] Means of 3 observations.

[3/] Means of 9 observations.

Table 43. Correlation Coefficients Obtained from a Step-Wise Regression Analysis of Applied Si, P and pH, Their Squares and Interactions, Soil and Plant Factors on Cane Yield at Nine Months as Indicated by R, R^2 x 100, and Simple Correlation Coefficients Between Those Factors and Yield

Variable	R1/	R^2 x 100	Simple Correlation Coefficients (r)
Applied Si	0.25	6	0.25*
Whole Plant Ca	0.35	12	-0.21
TCA Si (4 mo.)	0.41	17	0.03
Whole Plant Al	0.46	21	-0.19
TCA Si (9 mo.)	0.49	24	0.16
Whole Plant Mg	0.51	26	-0.24*
Soil Ca	0.54	29	0.12
Whole Plant Si	0.57	33	0.20
Sheath P (9 mo.)	0.62	38	-0.13
P x pH	0.64	42	0.07
Whole Plant P	0.69	47	-0.19
Sheath Al (9 mo.)	0.70	48	-0.16
Sheath Al (8 mo.)	0.70	49	0.06
Whole Plant K	0.71	51	0.02
Sheath Mg (8 mo.)	0.72	52	-0.15
Sheath Mg (4 mo.)	0.73	53	-0.14
Sheath P (8 mo.)	0.73	53	-0.02
Sheath K (8 mo.)	0.74	55	0.13
Sheath Mn (8 mo.)	0.75	56	-0.05
Sheath Si (4 mo.)	0.75	57	0.23*
Sheath Si (8 mo.)	0.76	58	0.14
Si^2	0.77	59	0.24*
Sheath K (9 mo.)	0.77	60	0.06
Whole Plant Mn	0.78	61	-0.06
Soil Si (H_2O)	0.79	63	0.17

1/ The R value applies to the relationship between the variable opposite it as well as all those above it and yield in a multiple regression analysis.

*Significant at the 5% level.

Table 44. Correlation Matrix of Yield and Selected Factors

	Yield	Soil Si (H_2O)	Soil Si (Mod. Truog)	TCA Si	Whole Plant Si	Soil P	Whole Plant P	Soil K	Whole Plant K	Soil Ca	Whole Plant Ca	Soil Mg	Whole Plant Mg	Soil Al	Whole Plant Al	Soil pH
Yield	1.00	.17	.24	.16	.20	.10	.20	-.01	.02	.12	-.21	.06	-.24	-.02	-.19	-.06
Soil Si (H_2O)		1.00	.65	.59	.80	.13	.08	.00	-.08	-.07	.13	-.10	-.01	-.06	.13	-.14
Soil Si (Mod. Truog)			1.00	.37	.50	.10	-.05	.16	-.04	.55	.20	.41	.06	-.40	.14	.46
TCA Sheath Si				1.00	.53	.08	.06	-.38	-.07	-.21	.14	-.11	.26	.11	.21	-.15
Whole Plant Si					1.00	.10	.24	-.09	-.02	-.11	.35	-.13	.20	.05	.10	-.16
Soil P						1.00	.67	.08	-.23	.24	.15	.18	-.01	-.12	-.07	.15
Whole Plant P							1.00	.06	.03	.16	.50	.07	.23	-.04	.07	.11
Soil K								1.00	-.03	.41	-.06	.40	-.27	-.26	-.07	.24
Whole Plant K									1.00	.06	.00	.04	.09	.04	.10	.10
Soil Ca										1.00	.18	.83	.09	-.68	.02	.92
Whole Plant Ca											1.00	.14	.57	-.08	.13	.16
Soil Mg												1.00	.36	-.57	-.14	.78
Whole Plant Mg													1.00	-.01	.07	.16
Soil Al														1.00	-.08	-.71
Whole Plant Al															1.00	.04
Soil pH																1.00

Table 45. Coefficients of Variation for All Factors and Yield of the Ratoon Sugarcane Crop

Variable	Coefficient	Variable	Coefficient
Green Sheath Weight (4)	9.19	Whole Plant Si	23.54
Green Sheath Weight (8)	7.58	Whole Plant N	15.23
Green Sheath Weight (9)	10.38	Whole Plant P	14.67
Sheath Moisture (4)	1.22	Whole Plant K	18.97
Sheath Moisture (8)	0.79	Whole Plant Ca	18.19
Sheath Moisture (9)	1.27	Whole Plant Mg	24.30
TCA Sheath Si (4)	14.82	Whole Plant Mn	29.19
TCA Sheath Si (8)	18.32	Whole Plant Al	56.30
TCA Sheath Si (9)	18.25	Soil pH	3.29
Sheath Si (4)	14.57	Soil Si (H_2O)	23.88
Sheath Si (8)	14.93	Soil Si (Mod. Truog)	26.56
Sheath Si (9)	15.17	Soil P	33.10
Sheath P (4)	11.65	Soil K	22.81
Sheath P (8)	20.79	Soil Ca	21.71
Sheath P (9)	18.70	Soil Mg	23.74
Sheath K (4)	15.68	Soil Al	64.00
Sheath K (8)	15.93	Yield	15.12
Sheath K (9)	17.52	Percent Dry Weight	5.09
Sheath Ca (4)	9.54	Si Uptake	26.18
Sheath Ca (8)	11.25	N Uptake	19.55
Sheath Ca (9)	12.69	P Uptake	13.07
Sheath Mg (4)	28.99	K Uptake	18.76
Sheath Mg (8)	29.21	Ca Uptake	16.26
Sheath Mg (9)	29.95	Mg Uptake	22.10
Sheath Mn (4)	27.01	Mn Uptake	30.09
Sheath Mn (8)	24.61	Al Uptake	51.14
Sheath Mn (9)	29.98	Sum Si Uptake	22.52
Sheath Al (4)	33.46	Sum P Uptake	11.10
Sheath Al (8)	77.93		
Sheath Al (9)	33.37		